Appendix F
Risk Assessment of Remedial
Alternatives

FINAL DRAFT

RISK ASSESSMENT OF REMEDIAL
ALTERNATIVES FOR THE
TYSON'S SITE
MONTGOMERY COUNTY, PENNSYLVANIA

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I. EXECUTIVE SUMMARY

A. Overview

The Tyson's Site in Upper Merion Township, Montgomery County, Pennsylvania is an abandoned sandstone quarry that was operated as a chemical waste disposal facility in the 1960's. During the past decade, the site has undergone numerous investigations to characterize the type and extent of contamination resulting from the past disposal practices. A U.S. Environmental Protection Agency (EPA) record of decision (ROD) issued in 1988 identified soil vapor extraction (SVE) as the selected alternative for remediating contaminated soils at the site. Between 1988 and the present, an SVE system was installed and resulted in the removal of nearly 200,000 pounds of volatile organic compounds (VOCs). Since 1993, however, the ability of the SVE system to efficiently remove the remaining contaminants has decreased significantly. The VOCs that remain in the soil are associated with zones through which air flow is limited.

To investigate the need for further action at the site, the responsible parties (RPs) at the Tyson's Site have been requested by EPA to conduct a Focused Feasibility Study (FFS) to identify and evaluate a final remedial alternative for the former lagoon area soils. Numerous remedial alternatives have been reviewed by the RPs, based on the feasibility of implementation and the effectiveness with respect to addressing contaminated soils at the Tyson's Site. Existing ground water contamination underlying the site is currently being addressed as a separate issue by the site RPs. More than 20 potentially applicable technologies for remediating contaminated soils at the site were preliminarily evaluated in the FFS, and the following five alternatives were selected for detailed analysis:

1) Soil cover, which involves removal of the SVE system, construction of a soil cover across contaminated areas of the site, revegetation of the site, and installation of protective fencing around the site;

2) Capping, which involves construction of a multi-layer cap (i.e., clay and soil) across contaminated areas of the site to eliminate the potential for direct contact with site soils and reduce volatile emissions of subsurface VOCs. A venting system will be installed below the least permeable layer (i.e., the clay

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layer) to allow for removal of vapors beneath this layer if there are indications that diffusion of these vapors through the cap may present an unreasonable health risk;

3) Wet soil cover, which includes an infiltration blanket and wet soil layer to minimize VOC emissions to the atmosphere, and a vegetated soil cover across the site;

4) On-site Low Temperature Thermal Desorption (LTTD), which involves excavation of contaminated soils in the unsaturated zone, on-site treatment of the excavated soil using LTTD, backfilling of the treated soil on-site, and construction of a soil cover across the backfilled areas; and,

5) Off-site incineration/disposal, which involves excavation of contaminated soils in the unsaturated zone, off-site transport by rail, thermal treatment of the excavated soil at an off-site location, backfilling of the excavated area with clean soil, construction of a soil cover across the site, and revegetation of the site.

EPA guidance (USEPA 1991a) recommends that during the review of remedial alternatives, human health risks associated with the implementation of the remedy (short-term risks) and with contamination remaining after completion of the remedy (long-term risks) should be evaluated. The objective of this report, therefore, is to present an assessment of risks associated with the remedial alternatives evaluated in the FFS using available data on site contamination, expected emission sources, and potentially exposed populations. When possible, this report assesses risks to the community and workers quantitatively. In some cases, however, sufficient data or methods are not available to provide quantitative estimates of risk. In such instances, a qualitative discussion of the sources of risk and the comparative likelihood of human health hazards is discussed.

B. Risk Assessment Process

The assessment of potential implementation and post-implementation human health risks associated with remedial alternatives proposed for the Tyson's Site as described in this report is based on guidelines developed by EPA and is consistent with well-established chemical risk assessment principles and procedures developed for the regulation of environmental contaminants (NRC 1983; OSTP 1985; USEPA 1986a; USEPA 1986b). Various EPA risk assessment guidance documents were used in conducting this risk

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assessment including the *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A* (USEPA 1989) and *Part C, Risk Evaluation of Remedial Alternatives* (USEPA 1991a). Part C was developed to provide an overview of the methods for estimating short- and long-term risks associated with implementation of remedial alternatives. Other EPA guidance that was relied upon include recently developed exposure assessment guidelines, including *Guidance on Risk Characterization for Risk Managers and Risk Assessors* (USEPA 1992a) and the *Guidelines for Exposure Assessment* (FR 57: 22887-22938). In addition, other related exposure assessment guidance documents, such as the *Exposure Factors Handbook* (USEPA 1990) and *Dermal Exposure Assessment: Principles and Applications* (USEPA 1992b) were used. The following sections briefly describe the individual steps in the risk assessment process:

1. **Hazard Identification**

    In the first step of the risk assessment, substances of potential concern associated with the site are identified. For the Tyson's Site, seven chemicals were identified and used in this analysis:

    - Benzene
    - Ethylbenzene
    - Toluene
    - Xylenes
    - Trichloroethene (TCE)
    - 1,2,3-Trichloropropane (TCP)
    - Tetrachloroethene (PCE)

2. **Toxicological Assessment**

    In the toxicological assessment step of the risk assessment, the relationship between the dose of an environmental contaminant received by an exposed individual and the human health response is evaluated for each substance of potential concern and is expressed in terms of a toxicity value. Toxicity values for the chemicals of potential concern were derived from EPA-compiled data (USEPA 1994a; IRIS 1994). For TCP, however, EPA has not published a verified toxicity value. Based on discussions with EPA Region III, a cancer slope factor of 7.0 $(mg/kg\text{-}d)^{-1}$ was used to assess risks by the oral and inhalation exposure pathways.

3. **Exposure Assessment**

    Exposure assessment involves the identification of potential exposure

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populations and pathways, estimation of concentrations of the chemicals of potential concern in various media, and quantification of exposure to the chemicals of potential concern in terms of an exposure dose.

a.   **Exposure Populations and Pathways**

Populations that could potentially be exposed to contaminants originating from the site that are evaluated in this risk assessment include:

1)   Off-site residents;

2)   Children in the 6 to 12-year-old age group, who trespass on-site after completion of the remedy;

3)   Maintenance workers, who visit the site on a regular basis after implementation of the remedy (or after installation of the ground water treatment system); and,

4)   Remedial workers, who may be exposed to hazards during implementation of the remedial alternative.

Quantitative estimates of exposures were developed for the off-site resident, trespasser, and maintenance worker, and a qualitative assessment of worker hazards was performed for the remedial worker.

b.   **Estimation of Environmental Concentrations**

In order to estimate exposure, it is necessary to estimate concentrations of contaminants in environmental media, such as soil and air. Soil concentrations were characterized based on 1988 subsurface soil sampling data and recent (1993) surficial soil sampling data compiled by Environmental Resources Management, Inc. (ERM 1989;1993). EPA-recommended vapor emissions models were used to estimate the volatilization of chemicals of potential concern to the atmosphere, and the Industrial Source Complex Long-Term (ISCLT2) air dispersion model was applied to simulate transport of airborne chemicals in order to estimate off-site air concentrations.

c.   **Estimation of Human Exposure**

Exposure to populations that may come in contact with chemicals of potential concern on-site or emanating from the site was quantified by

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combining exposure factors (e.g., intake rates, exposure duration) that reflect activity and behavior patterns of the exposed population. Average exposure was estimated by combining typical exposure factors that represent the median of the range of possible values for each factor. In doing so, exposure that approximates the median of the exposure distribution of the population is estimated. Reasonable maximum exposure (RME) was also characterized using Superfund exposure assessment guidelines.

4. Risk Characterization

The final step of the risk assessment process involves the calculation of numerical estimates of average and reasonable maximum cancer risk and the potential for noncarcinogenic health effects for each chemical of potential concern by each potential exposure pathway. The potential for human health effects to occur is estimated by combining the toxicity values compiled in step (2) and the exposure dose estimates derived in step (3). The results of the risk characterization for this risk assessment are summarized in the following section.

C. Summary of Results

The potential for human health risks associated with remedy implementation was assessed to provide a quantitative basis for differentiating between the remedial alternatives evaluated in the FFS, consistent with the statutory health protectiveness criteria used in remedy selection. Residual risks associated with contaminants remaining on-site after completion of the remedy were also considered in this evaluation. As described in the uncertainties section and throughout this report, there are limitations in the understanding of the toxicity of and exposure to chemicals at the site which has necessitated the use of conservative assumptions in conducting the risk assessment. Consequently, while the risk assessment may be used as a basis for comparing the alternatives, this assessment is not intended to provide absolute measures of risk, particularly given the limitations associated with derivation of a potency factor for TCP as described in Chapter IX. In addition, the combination of conservative assumptions used to account for the uncertainty will overstate risks.

Four of the seven chemicals of potential concern evaluated in this risk assessment (benzene, PCE, TCE and TCP) have been classified by EPA as carcinogens. For three of these compounds (benzene, PCE and TCE), the estimated lifetime cancer risks are not significant for any of the remedial alternatives evaluated. Also, exposure to noncarcinogenic

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chemicals from the site during implementation and post-implementation periods is unlikely to result in adverse health effects for any of the remedial alternatives.

Lifetime cancer risks associated with exposure to TCP are estimated to be within or below EPA's discretionary range of 1×10^{-6} to 1×10^{-4}. Among the routes of exposure evaluated (inhalation, soil ingestion, and dermal contact with soil), inhalation is by far the most significant exposure pathway contributing to the estimated cancer risks. Table 1 provides a summary of the cumulative TCP lifetime cancer risk estimates for the remedial alternatives due to inhalation. In addition, the total TCP inhalation risk (implementation and post-implementation risks combined) for each alternative is shown.

The following are the conclusions of the report from an analysis of the estimated risks associated with the remedial alternatives:

- Despite engineering efforts to minimize the risks associated with excavation, implementation cancer risks associated with the excavation and treatment alternatives exceed 1×10^{-5}. These intrusive remedies also pose increased risks of injury to workers due to accidents and heat stress/heat stroke from working within the soil processing enclosure.

- In comparison, because of the noninvasive nature of the soil cover, capping (with and without a venting system), and wet soil cover alternatives, the estimated implementation cancer risks for these alternatives are below 1×10^{-6}.

- Post-implementation total cancer risks for the off-site resident are comparable for the soil cover, on-site LTTD, and off-site incineration/disposal alternatives (between 1×10^{-5} and 8×10^{-5}). Post-implementation total cancer risks are approximately an order of magnitude less for the capping without venting alternative. Total risks for the capping with venting and the wet soil cover alternatives are below 1×10^{-6}.

- Post-implementation risks in the range of 1×10^{-6} to 1×10^{-4} are primarily because of TCP vapor emissions from DNAPL in the bedrock or the overlying soils that diffuse through the fill material into the atmosphere. A clay cap or wet soil cover provides a significant barrier to this migration; consequently, the estimated cancer risks for the capping alternative is significantly lower than post-implementation risks associated with the soil cover, on-site LTTD, and off-site incineration/disposal alternatives. Emissions through the soil cover were estimated to be insignificant; therefore, a

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	TABLE 1					
	Summary of the Implementation, Post-Implementation, and Total Lifetime Cancer Risks Due to TCP Inhalation Exposure					
Exposure Population	**Remedial Alternative**					
	Soil Cover	**Capping without Venting**	**Capping with Venting**[a]	**Wet Soil Cover**	**On-site LTTD**	**Off-site Incineration/ Disposal**
Implementation						
Off-Site Resident						
Average	1×10^{-7}	1×10^{-7}	1×10^{-7}	1×10^{-7}	2×10^{-5}	2×10^{-5}
RME	2×10^{-7}	2×10^{-7}	2×10^{-7}	2×10^{-7}	4×10^{-5}	4×10^{-5}
Remedial Worker	NA	NA	NA	NA	Qualitative Evaluation	
Post-Implementation						
Off-Site Resident						
Average	1×10^{-5}	1×10^{-6}	7×10^{-8}	NA	7×10^{-6}	7×10^{-6}
RME	3×10^{-5}	5×10^{-6}	2×10^{-7}		2×10^{-5}	2×10^{-5}
Maintenance Worker						
Average	2×10^{-5}	2×10^{-6}	1×10^{-7}	NA	1×10^{-5}	1×10^{-5}
RME	8×10^{-5}	1×10^{-5}	6×10^{-7}		6×10^{-5}	6×10^{-5}
Trespassing Child						
Average	3×10^{-6}	5×10^{-7}	2×10^{-8}	NA	2×10^{-6}	2×10^{-6}
RME	1×10^{-5}	1×10^{-6}	7×10^{-8}		7×10^{-6}	7×10^{-6}
Total Inhalation Risks						
Off-Site Resident						
Average	1×10^{-5}	2×10^{-6}	2×10^{-7}	1×10^{-7}	3×10^{-5}	3×10^{-5}
RME	3×10^{-5}	5×10^{-6}	4×10^{-7}	2×10^{-7}	6×10^{-5}	6×10^{-5}
Maintenance Worker						
Average	2×10^{-5}	2×10^{-6}	1×10^{-7}	NA	1×10^{-5}	1×10^{-5}
RME	8×10^{-5}	1×10^{-5}	6×10^{-7}		6×10^{-5}	6×10^{-5}
Trespassing Child						
Average	3×10^{-6}	5×10^{-7}	2×10^{-8}	NA	2×10^{-6}	2×10^{-6}
RME	1×10^{-5}	1×10^{-6}	7×10^{-8}		7×10^{-6}	7×10^{-6}

NA - Not applicable; significant emissions are not anticipated.

a - There is a provision under the capping alternative for activating a vent system installed below the cap as a contingency measure in the event there are indications that the risk may be unacceptable.

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quantitative analysis of post-implementation inhalation risks for this alternative was not conducted.

- The off-site incineration/disposal alternative is the only remedial alternative with an off-site disposal component that has the associated risk of accidents, injuries, and fatalities due to incidents occurring during rail transport. The likelihood of an accident during rail transport to off-site facilities ranged from 1.5 percent to 2.3 percent for the two incineration/disposal facilities considered in this assessment. The likelihood of injuries and fatalities ranged from 3.2 percent to 4.9 percent and 1.1 percent to 1.7 percent, respectively.

- The short-term implementation risks associated with the excavation remedies outweigh any perceived long-term risk reduction afforded by these intrusive alternatives. This is especially true at the Tyson's Site where topographic features at the site would hinder excavation activities and complicate the implementation of mitigating measures, such as excavation within an enclosure, to minimize emissions.

- Because of the presence of significant quantities of DNAPL in bedrock fissures underlying the site, there is a strong likelihood that clean backfill will be recontaminated over time, thereby reducing the long-term benefits of a removal alternative (AGRL 1994).

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II. INTRODUCTION

A.   Overview

The Tyson's Site in Upper Merion Township, Montgomery County, Pennsylvania is an abandoned sandstone quarry that was operated as a chemical waste disposal facility in the 1960's. The four-acre site is approximately 15 miles northwest of Philadelphia and is located adjacent to a Conrail switching yard across the Schuylkill River from Norristown, Pennsylvania. The former lagoon area of the site is divided into four sub-areas, referred to in this report as the upper and lower west, and upper and lower east, as shown in Figure 1.

During the past decade, the site has undergone numerous investigations to characterize the type and extent of contamination resulting from the past disposal practices. A ROD issued by EPA in 1988 identified SVE as the selected alternative for remediating contaminated soils at the site. Between 1988 and the present, an SVE system was installed and resulted in the removal of nearly 200,000 pounds of VOCs. Since 1993, however, the ability of the SVE system to efficiently remove the remaining contaminants has decreased significantly. The VOCs that remain in the soil are generally associated with zones through which air flow is limited.

To investigate the extent of any further action at the site, the RPs at the Tyson's Site have been requested by EPA to conduct an FFS to identify and evaluate other remedial alternatives for the former lagoon area soils. EPA guidance (USEPA 1991a) recommends that during the review of remedial alternatives, human health risks associated with the implementation of the remedy (short-term risks) and with contamination remaining after completion of the remedy (long-term risks) should be evaluated. The guidance further states, however, that the level of effort (i.e., qualitative, semi-quantitative, or quantitative) undertaken in the assessment is left to the discretion of the risk assessor, depending primarily on: 1) the importance of risk in the decision-making process; and 2) the perceived risk of the alternatives (p. 14, USEPA 1991a).

At the Tyson's Site, risk will play an important role in the comparison of remedial alternatives, because of the presence of potentially toxic chemicals, the proximity of local populations, and the potential for chemical releases associated with several of the alternatives. A quantitative risk assessment of remedial alternatives, therefore, was

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LOWER
EAST

UPPER
EAST

TERRA VAC
TREATMENT
FACILITY

UPPER
WEST

LOWER
WEST

0   120   240

Scale in Feet

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SUB-AREAS OF THE TYSON'S SITE

Figure
1
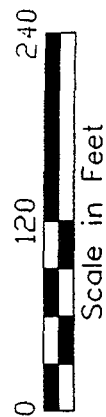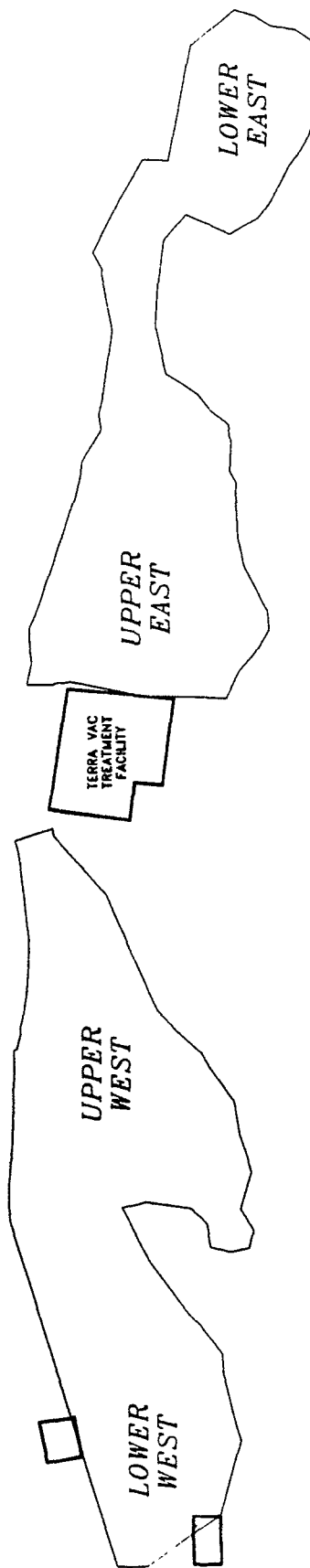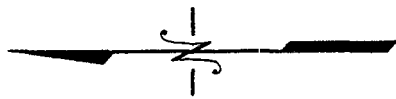
performed using available data on site contamination, expected emission sources, and potentially exposed populations. However, rather than conduct an exhaustive evaluation of every potential exposure pathway, professional judgment was applied to include exposure pathways and populations that primarily contribute to and reflect the potential risks at the site as discussed herein. Thus, this quantitative risk assessment provides an additional source of information (i.e., basis for comparison) for the decision maker in differentiating between the remedial alternatives being evaluated in the FFS.

The objective of this report, therefore, is to present the results of an analysis of the short-term (implementation) and long-term (post-implementation) human health risks associated with the remedial alternatives selected for evaluation in the FFS. Short-term risks are those hazards that are associated with the implementation of a remedial alternative and may involve both chemical exposure risks (carcinogenic and non-carcinogenic) and physical hazards to workers involved in the remediation. Long-term risks refer primarily to human health risks associated with residual contamination remaining at the site after completion of the remedy. When possible, this document assesses risks to the community and workers quantitatively. In some cases, however, sufficient data or methods are not available to provide quantitative estimates of risk. In such instances, a qualitative discussion of the sources and the comparative likelihood of human health hazards is discussed.

The risk assessment has been conducted consistent with methods prescribed by EPA in guidance documents. However, it should be noted that the risk assessment is based on site-specific information and data provided to ENVIRON. ENVIRON has not conducted any independent data collection efforts; consequently, this report is accurate and complete to the extent that the data obtained from other sources are accurate and complete.

B.   Remedial Alternatives

This document presents the methodologies and results of the risk assessment for the following alternatives evaluated in the FFS:

1)   Soil cover, which involves construction of a soil cover across contaminated areas of the site, revegetation of the site, and installation of protective fencing around the site;

2)   Capping, which involves construction of a multi-layer cap (i.e., clay and soil) across contaminated areas of the site to eliminate the potential for direct contact with site soils and reduce volatile emissions of subsurface VOCs. A venting system will be installed below the least permeable layer (i.e., the clay

layer) to allow for removal of vapors beneath this layer if there are indications that diffusion of these vapors through the cap may present an unreasonable health risk. In addition, the site will be revegetated and fenced;

3) Wet soil cover, which includes an infiltration blanket to maintain a wet soil layer that minimizes VOC emissions to the atmosphere. A vegetated soil cover and fencing are also included;

4) On-site Low Temperature Thermal Desorption (LTTD), which involves excavation of contaminated soils in the unsaturated zone, on-site treatment of the excavated soil using LTTD, backfilling of the treated soil on-site, construction of a vegetated soil cover across the backfilled areas, and installation of fencing; and,

5) Off-site incineration/disposal, which involves excavation of contaminated soils in the unsaturated zone, off-site transport by rail, thermal treatment of the excavated soil and disposal of the resulting ash at an off-site location, backfilling of the excavated area with clean soil, construction of a vegetated soil cover across the site, and installation of fencing.

C. Report Organization

The remainder of this risk assessment is divided into the following chapters:

Chapter III. Risk Assessment Methodology, which describes the procedures used in assessing the potential for human health risks, and identifies populations potentially exposed to site-related contaminants.

Chapter IV. Description of Remedial Alternatives, which provides a description of each of the alternatives evaluated in the FFS and the associated assumptions used in the risk assessment.

Chapter V. Estimation of Exposure Dose, in which estimates of chemical concentrations at points of potential human exposure are combined with exposure assumptions (e.g., rate of chemical intake, and the characteristics of the exposed population) to arrive at estimates of exposure dose.

Chapter VI. Risk Characterization, in which numerical estimates of carcinogenic risk and the potential for noncancer health effects are calculated for each chemical of potential

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concern by each route of potential exposure using toxicity information and estimates of human exposure.

Chapter VII. <u>Other Concerns Associated with Remediation Activities</u>, in which potential sources of hazards and health risks to remedial workers are identified and evaluated qualitatively and semi-quantitatively.

Chapter VIII. <u>Risks Associated with Rail Transport</u>, in which risks associated with rail transport of excavated soil to an off-site incineration location are evaluated and expressed in terms of the number of accidents, injuries, and fatalities expected to occur during the transport process.

Chapter IX. <u>Uncertainties and Limitations</u>, in which the uncertainties associated with the risk assessment process, in general, and with this specific assessment are identified. A sensitivity analysis to evaluate uncertainties in the risk assessment is discussed.

Appendix A: <u>Estimation of Soil Concentrations</u>, in which the methodology that was used to estimate soil concentrations applicable to the risk assessment is presented and the soil concentrations used in the risk assessment are summarized.

Appendix B: <u>Estimation of Emission Rates</u>, in which the vapor emissions equations used to model the transport of contaminant vapors to the atmosphere are described and associated site-specific assumptions are summarized.

Appendix C: <u>Simulation of Contaminant Transport</u>, in which the air dispersion model and the associated assumptions used to estimate downwind and on-site vapor concentrations are described.

Appendix D: <u>Exposure Dose Summary Tables</u>, in which the exposure doses estimated in Chapter V are summarized.

III. RISK ASSESSMENT METHODOLOGY

A. Risk Assessment Process

The assessment of potential implementation and post-implementation human health risks associated with remedial alternatives proposed for the Tyson's Site as described in this report is based on guidelines developed by EPA and is consistent with well-established chemical risk assessment principles and procedures developed for the regulation of environmental contaminants (NRC 1983; OSTP 1985; USEPA 1986a; USEPA 1986b). Application of these guidelines and principles provides a consistent process for evaluating and documenting potential health risks associated with environmental exposures.

This risk assessment of remedial alternatives is composed of the following steps:

1) Hazard Identification, in which the substances of potential concern associated with the site are identified;

2) Toxicological (Dose-Response) Assessment, in which the relationship between the dose of an environmental contaminant received by an exposed individual and the human health response is evaluated for each substance of potential concern;

3) Exposure Assessment, in which potential exposure populations and pathways are identified, the concentrations of the substances of potential concern at the site are estimated, and exposure to the substances of potential concern is calculated; and,

4) Risk Characterization, in which numerical estimates of cancer risk and the potential for noncarcinogenic health effects are calculated for each substance by each potential route of exposure. Uncertainties and limitations associated with the exposure and risk assessment process are also evaluated in the risk characterization.

Various EPA risk assessment guidance documents were used in conducting this risk assessment including the *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A* (USEPA 1989) and *Part C, Risk Evaluation of Remedial*

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Alternatives (USEPA 1991a). Part C was developed to provide an overview of the methods for estimating short- and long-term risks associated with implementation of remedial alternatives. Other EPA guidance that was relied upon include recently developed exposure assessment guidelines, including *Guidance on Risk Characterization for Risk Managers and Risk Assessors* (USEPA 1992a) and the *Guidelines for Exposure Assessment* (FR 57: 22887-22938). In addition, other related exposure assessment guidance documents, such as the *Exposure Factors Handbook* (USEPA 1990) and *Dermal Exposure Assessment: Principles and Applications* (USEPA 1992b) were used. The following sections briefly describe the individual steps in the risk assessment process listed above.

B. Hazard Identification

In the first step of the risk assessment, hazard identification, chemical substances that have been detected at the site and may pose a potential threat to human health are identified (i.e., a list of chemicals of potential concern is developed). The purpose of identifying such substances is to provide a manageable list of substances for which human health risks will be quantified. ENVIRON identified seven chemicals that have been detected frequently during surficial and subsurface soil sampling episodes at the Tyson's Site and are known to present potential health hazards. The chemicals of potential concern include:

- Benzene
- Ethylbenzene
- Toluene
- Xylenes
- Trichloroethene (TCE)
- 1,2,3-Trichloropropane (TCP)
- Tetrachloroethene (PCE)

Although other substances have been detected at the site, they are considered to be less toxic or less prevalent than those selected and would not have a substantial impact on the outcome of the risk assessment, based on the results of previous risk assessments performed at the site.

C. Toxicity Assessment

In the second step of the risk assessment, the relevant scientific literature is examined to determine the effects in humans or laboratory animals from exposure to chemicals as a function of exposure concentration. EPA has conducted such assessments on numerous chemicals that are frequently detected in environmental samples, and publishes findings that

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are regularly updated (USEPA 1994a; IRIS 1994). Consequently, EPA has developed reference doses (RfDs) for chemicals with noncarcinogenic health effects and slope factors for chemicals that have exhibited carcinogenic health effects. RfDs (generally expressed as a dose in mg/kg-day) are EPA's estimate of the daily human exposure that is unlikely to result in deleterious effects following chronic exposure. In addition, EPA has developed Slope Factors (SFs) for chemicals that have exhibited carcinogenic effects in either animal or human studies. The RfDs and SFs that have been published by EPA for the chemicals of potential concern considered in this risk assessment are presented in Table 2 (USEPA 1994a; IRIS 1994). Brief discussions of the methodologies for assessing the toxicity of carcinogens and noncarcinogens are presented in the following sections.

1.   **Toxicity Assessment for Noncancer Effects**

An RfD is EPA's estimate of the daily human exposure that is unlikely to result in harmful effects following chronic exposure. The basic approach for developing RfD values for noncarcinogenic effects of substances is based on the belief that some minimum (threshold) exposure level must be reached before the effect will occur, i.e., that protective mechanisms exist that must be overcome before an adverse health effect can occur. The methodology used in developing an RfD value for noncarcinogenic effects, therefore, involves identifying or estimating this threshold level. Unless adequate human data are available, an RfD is generally based on a study from the most sensitive animal species tested and the most sensitive endpoint measured. From this critical study, the experimental exposure representing the highest dose level tested at which no adverse effects were demonstrated (the no-observed-adverse-effect level, NOAEL) is identified. In some studies, only a lowest-observed-adverse-effect level (LOAEL) is available. The RfD is derived from the NOAEL or LOAEL for the critical toxic effect by dividing the NOAEL or LOAEL by uncertainty factors. These factors generally are multiples of 10, with each factor representing a specific area of uncertainty in the extrapolation from the available study data. For example, a 100-fold uncertainty factor is typically used when the RfD is based on results from long-term animal studies which have been extrapolated to humans. Additional factors of 10 are applied when there are limitations in the available experimental data.

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TABLE 2				
Oral and Inhalation Toxicity Values for Chemicals of Potential Concern				
Chemical	Oral Slope Factor (mg/kg-day)$^{-1}$	Oral RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)$^{-1}$	Inhalation RfD (mg/kg-day)
Benzene	2.9×10^{-2}	NA	2.9×10^{-2}	NA
Ethylbenzene	NA	1.0×10^{-1}	NA	3.0×10^{-1}
Tetrachloroethene	5.2×10^{-2}	1.0×10^{-2}	2.0×10^{-3}	1.0×10^{-2}*
Toluene	NA	2.0×10^{-1}	NA	1.0×10^{-1}
Trichloroethene	1.1×10^{-2}	NA	6.0×10^{-3}	NA
1,2,3-Trichloropropane	7.0**	6×10^{-3}	7.0*	6×10^{-3}*
Xylenes	NA	2.0	NA	2.0*

* - Estimated based on route-to-route extrapolation.
** - The slope factor for TCP is based on EPA Region III recommendation.

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2. Toxicity Assessment for Chemical Carcinogens

Unlike most noncarcinogenic health effects, carcinogens are considered by many scientists to pose a finite risk at all exposure levels. In evaluating cancer risks, therefore, a "no-threshold" assumption has been applied. It should be noted that the no-threshold assumption may not apply for some classes of carcinogens that act through a mechanism that requires a threshold dose to be exceeded prior to initiation of the carcinogenic process. For purposes of this assessment, however, the no-threshold assumption has been assumed for all chemical carcinogens.

In assessing carcinogenic potential, a two-part evaluation is used in which the first step involves evaluating the likelihood that the substance is a human carcinogen (i.e., a weight-of-evidence assessment) and the second step involves defining the quantitative relationship between dose and response (i.e., development of a slope factor). In the first step, EPA classifies a chemical into one of five groups that indicate the likelihood that the chemical is a carcinogen, based on the weight of evidence from human and animal investigations. Those chemicals that are determined to be known, probable, or potential carcinogens are further evaluated. The outcome of the second part of the evaluation determines the potency of the carcinogen. The slope factor represents the upper 95 percent confidence limit on the linear component of the slope of the tumorigenic dose-response curve in the low-dose (low-risk) region. Unlike the RfD in noncancer risk assessment, the slope factor is an upper bound estimate of the likelihood that a response will occur per unit intake of a chemical over a 70-year lifetime and is derived by applying a mathematical model to extrapolate from the relatively high doses administered to experimental animals to the lower exposure levels expected for human contact in the environment. A number of low-dose extrapolation models have been developed. EPA generally uses the linearized multistage model in the absence of adequate information to support some other model.

3. Toxicity of 1,2,3-Trichloropropane

At present, EPA has not published a verified toxicity value for TCP. However, based on discussions with EPA Region III, a cancer slope factor of 7.0 $(mg/kg-d)^{-1}$ will be used to assess risks by the oral and inhalation exposure pathways. Uncertainties associated with the EPA estimate of the cancer potency of TCP arise from several major areas, including: 1) high to low-dose extrapolation; 2) interspecies extrapolation; 3) inter-route extrapolation; and, 4) species/tissue specificity of tumorigenic effects. These uncertainties all tend to exaggerate the potency estimate,

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suggesting that the true potency of TCP may be lower than that calculated by EPA. Specific details concerning these sources of uncertainty are discussed in Chapter IX.

D.   Exposure Assessment

The third step of the risk assessment process, exposure assessment, includes the identification of exposure populations and pathways, estimation of environmental concentrations, and estimation of exposure dose through the characterization of the amount, frequency, and duration of human exposure. This involves: 1) identifying groups of individuals that are likely to come into contact with contaminants at or from the site; 2) estimating the concentrations of chemicals of potential concern in environmental media with which human contact may occur; and, 3) characterizing the behavior and activity patterns of individuals in this group (exposure population) that may affect the amount of exposure to these media. This information is combined to provide a quantitative estimate of exposure (referred to as the dose) that, in turn, is compared with the experimentally derived toxicity estimates from step 2.

1.   Identification of Exposure Populations and Pathways

Exposure to contaminants in soil at the Tyson's Site may occur through inhalation of vapors emitted during soil excavation/handling activities or as a result of vapor diffusion processes. In addition, direct soil contact may lead to both dermal and ingestion exposures. Given the existing site conditions, contaminants in soil are not anticipated to significantly influence concentrations in ground water, so that exposure to contaminated soil and air are the only pathways of potential concern considered in this risk assessment (see Appendix A, ENVIRON 1994).

It is anticipated that the final remedy selected for the site will include deed restrictions or institutional controls that limit future use. Future residential development of the former lagoon area is precluded primarily due to long-term environmental conditions (e.g., ground water and bedrock contaminated with DNAPL). Long-term control for access to the former lagoon area will be required to facilitate operation and maintenance of both current and future remedial activities which are expected to extend beyond thirty years. This will necessitate restrictions on future property uses. Towards this end, Ciba-Geigy has gained full control of the former lagoon area through an Easement Agreement with the current property owner, T.A. Raymond. Therefore, since residential use is unlikely to occur, exposure associated with residential development of the former lagoon area will not be

considered in this risk assessment (see Appendix B, ENVIRON 1994).

Populations that could potentially be exposed to contaminants originating from the site and are evaluated in this risk assessment include:

1) Off-site residents, who may be exposed to vapors emanating from the former lagoon area soils during and after implementation of the remedial alternative;

2) Children in the 6 to 12-year-old age group, who trespass on-site after completion of the remedy and are exposed to contaminants in air and soil;

3) Maintenance workers, who visit the site on a regular basis after implementation of the remedy (or after installation of the ground water treatment system) and are exposed to contaminants in soil and air; and,

4) Remedial workers, who may be exposed to hazards during implementation of the remedial alternative.

Risks to off-site residents are estimated for both implementation of the remedy (short-term risks) and for the post-implementation period (long-term risks). In both instances, exposure due to inhalation of vapors that are emitted from the site and are transported off-site will be quantified. Measures will be taken to adequately secure the site to prevent trespassing on-site during implementation of the remedy (e.g., fencing and site security). Therefore, direct contact with contaminated soil by residents is not expected to occur during implementation.

Following implementation of the remedial alternative, appropriate measures will be taken to adequately secure the site; however, it is remotely possible that children may trespass on the site. Trespassing children may be exposed to vapors emitted from subsurface soils and direct dermal contact with and ingestion of uncovered, contaminated soil. These potential routes of exposure are considered in this risk assessment.

As noted earlier, it is anticipated that after implementation of the remedy the site will be used in the future to support the ground water remedy. Thus, after implementation of the remedial alternative, potential on-site exposures may occur to a maintenance worker who visits the site routinely to perform such activities as assessing the integrity of the soil cover or cap, checking the condition of the security fencing, and operating equipment that may be located on-site. During the brief

periods when the maintenance worker is on-site, it is assumed that potential exposure may occur due to chemicals that volatilize from subsurface soils and from ingestion of and dermal contact with contaminated soil.

For individuals working on-site during implementation of the remedy, it is assumed that adequate protection against routine exposure to chemicals will be provided. Other hazards to workers, however, such as accidental acute chemical exposure, heat stress, noise, and equipment accidents that may occur during implementation of the remedy are evaluated qualitatively in this risk assessment.

In summary, quantitative estimates of exposures will be developed for the off-site resident, trespasser, and maintenance worker. Table 3 summarizes the exposure populations and pathways that are considered in the risk assessment of remedial alternatives.

2. Estimation of Environmental Concentrations

Extensive sampling at the Tyson's Site has indicated the presence of various organic compounds in subsurface soils. Remediation activities have extracted a significant portion of these compounds; however, relatively high concentrations of several compounds still may be found in deeper soil layers at the site. Future remedial activities at the site may cause releases of these compounds to the atmosphere. Subsequently, airborne chemicals are transported to off-site locations where exposure may occur. In addition, exposure may occur due to direct contact with soils.

In order to quantify this exposure, concentrations of chemicals of potential concern in site soils are estimated in this report based on soil sampling data collected on-site. To compensate for the uncertainty in the estimation process, conservative assumptions were applied that provide a range (average and reasonable maximum) of soil concentrations on-site. The methodology used to characterize site soils is presented in Appendix A.

Soil handling activities and passive diffusion will cause compounds in soil to volatilize and be transported off-site. The methodology used to estimate emissions from the former lagoon areas is presented in Appendix B. Based on the estimated emission rates for the substances of potential concern from soil, air concentrations are estimated by simulating off-site transport of substances released from site soils using the EPA-approved Industrial Source Complex (ISC2) air dispersion model in the long term mode (ISCLT2). The methodology used to simulate off-site transport of

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TABLE 3 Exposure Pathways and Populations Considered in the Risk Assessment of Remedial Alternatives					
Population/Pathway	**Remedial Alternative**				
	Soil Cover	**Capping**	**Wet Soil Cover**	**On-Site LTTD**	**Off-Site Incineration/ Disposal**
Off-Site Resident Inhalation	S/L	S/L	S[a]	S/L	S/L
Trespasser Inhalation	L	L	NA[a]	L	L
Ingestion	L	NA[b]	L	L	L
Dermal	L	NA[b]	L	L	L
Maintenance Worker Inhalation	L	L	NA[a]	L	L
Ingestion	L	NA[b]	L	L	L
Dermal	L	NA[b]	L	L	L
Remedial Worker[b] (in enclosure) Inhalation	NA	NA	NA	S[c]	S[c]

a - Due to the predicted downward percolation of water associated with this remedy, significant emissions are not anticipated; therefore, long-term risks were not evaluated.

b - The multilayer cap is anticipated to adequately protect individuals on-site from direct contact exposure (i.e., ingestion and dermal contact) to surficial soils.

c - The greatest potential for significant exposure to the remedial worker is expected in the enclosure. The evaluation of risk is limited to qualitative and semi-quantitative analyses.

NA - Not applicable; significant exposure not anticipated.

S - Short-term risks evaluated

L - Long-term risks evaluated

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chemicals by air dispersion is presented in Appendix C.

The concentrations estimated for environmental media on-and off-site are used, subsequently, to estimate the magnitude of human exposure. The following chapters of this assessment describe the methods used to estimate soil concentrations, vapor emissions, and on- and off-site air concentrations.

3. Estimation of Exposure Dose

The magnitude of human exposure to site-related compounds is assessed through a number of exposure pathways. Exposure pathways describe the circumstances under which a population may potentially be exposed to substances originating from the site. The potential exposure pathways for the Tyson's Site are identified and, subsequently, the associated human exposure (dose) is estimated. To estimate dose, conservative assumptions concerning the rate, frequency, and duration of exposure are developed, based on EPA-recommended values representing human behavior and activity patterns. EPA values for various exposure parameters, such as inhalation rate, soil ingestion rate, and exposure duration are derived from EPA guidance documents (listed earlier). Conservative exposure assumptions are combined with the estimates of environmental concentrations to provide an upper bound estimate of human dose to site-related substances of potential concern. These doses are, in turn, compared to EPA toxicity values in the risk characterization step.

E. Risk Characterization

The final step of the risk assessment integrates information generated in the previous steps. To determine the likelihood of noncancer effects, the exposure dose (derived in step 3) for a chemical of potential concern is compared with the chemical-specific RfD. The ratio of the exposure dose for a specific chemical to the RfD is defined as the hazard quotient.

The excess lifetime cancer risk resulting from exposure to site-related carcinogenic substances of potential concern is estimated by the product of the lifetime average daily dose and the slope factor, SF, for the specific carcinogen. In cases of multiple chemical exposures, it will be assumed that cancer risks are additive (USEPA 1986a).

Acute noncancer health effects may occur to remedial workers during remedy implementation if an accident were to occur that compromised the integrity of their protective equipment. Predicted exposures under these circumstances were compared with acute standards such as exposure levels that are immediately dangerous to life or health (IDLH) as determined by the National Institute of Occupational Safety and Health (NIOSH).

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IV. DESCRIPTION OF REMEDIAL ALTERNATIVES

A. Overview

Numerous remedial alternatives have been reviewed by the RPs, based on the feasibility of implementation and the effectiveness with respect to addressing contaminated soils at the Tyson's Site. More than 20 potentially applicable technologies for remediating contaminated soils at the site were preliminarily evaluated in the FFS, and five alternatives were selected for detailed analysis. The following sections provide a description of each of the alternatives and the associated assumptions used in the risk assessment. In addition, potential sources of exposure for which risks are evaluated are identified for each alternative.

The alternatives evaluated in the FFS assume cessation of SVE operations and removal of all above-ground piping and equipment associated with the SVE system. These activities are not expected to result in significant emissions of VOCs or present a significant potential for direct contact with contaminated soils. Therefore, risks associated with implementation of the remedies will be estimated for the period after removal of the SVE system.

B. Alternative 1 - Soil Cover

The SVE system has successfully removed almost 200,000 pounds of VOCs from the east and west former lagoon area soils, and based on recent sampling results (at three inches and two feet), surficial soils in the former lagoon areas contain relatively low concentrations of the chemicals of potential concern. The soil cover alternative further reduces the potential for direct contact with soil contaminants through installation of a protective barrier in the form of a soil cover. Implementation of this remedy involves several steps, as follows:

1) Grading - Preparation of the site will primarily include grading to create a more level surface for installation of the soil cover and sedimentation pond. The grading will involve both cutting and filling of small volumes of relatively uncontaminated soil (approximately 500 yd^3 and 2,100 yd^3, respectively). Fill material will be delivered to the site from off-site locations. The estimated duration of site preparation is 10 days; however, it is estimated that soil moving/handling (cutting) activities will occur

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over a 2-day period. On each day (8 hours), therefore, approximately 250 yd^3 will be removed and placed in areas requiring fill, resulting in an excavation rate of 0.0087 yd^3/sec (0.0066 m^3/sec). It is estimated that the total area of cut required for grading is 8,000 ft^2, or 4,000 ft^2 (370 m^2) per day (personal communication, ERM 1994). It is assumed that over the period of one day, this entire area will be exposed for an average duration of one-half day (14,400 seconds).

2)   Construction of Soil Cover - A soil cover will be installed across the former lagoon areas to promote growth of a vegetative cover and limit the likelihood of direct contact with underlying contaminated soils. No intrusive work and no potential source of significant exposure are expected during this activity. It is estimated that construction of the soil cover will require 6 weeks.

3)   Sedimentation Basin Construction - Sedimentation basins used to collect runoff from the soil cover will be constructed above ground level. No intrusive activities are expected during this period.

4)   Miscellaneous Post-construction Activities - The soil cover will be seeded to allow for vegetative growth, and site security (e.g., fencing) will be maintained for an indefinite period of time. No intrusive work or no potential sources of significant exposure are expected during this period.

Assumptions associated with the implementation of the soil cover alternative are summarized in Table 4.

During implementation of the soil cover alternative, it is estimated that exposure may be associated with two activities or sources: grading and passive diffusion. During grading, some minor soil handling/moving activities will occur in the upper two feet of soil. Although soil sampling has indicated that contaminant concentrations in this soil horizon are low, some low-level emissions of VOCs may be expected. In addition, once the SVE system is removed from operation, volatile constituents in the soil pore space that were formerly removed by the system will slowly diffuse upward. These types of emissions will continue until completion of the soil cover. Direct contact with contaminated soil during implementation of the soil cover alternative is not expected because on-site workers will be adequately protected and measures will be taken to prohibit access to the site by trespassers.

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After implementation of the remedy, passive diffusion of volatile constituents in subsurface soils will continue to occur through the soil cover. In addition, ingestion of and dermal contact with soil may occur if the soil cover does not completely cover all contaminated areas of the site. A summary of the potential sources of exposure associated with the soil cover alternative is presented in Table 6 at the end of this chapter.

C.   Alternative 2 - Capping

Implementation of the capping alternative involves several activities including: construction of runoff collection basins (sedimentation basins) and grading; and installation of a multilayer cap, which includes a venting layer constructed beneath the least permeable layer of the cap to capture volatile constituents in soil pore space that diffuse upward. The venting layer will be connected to a vapor treatment system (e.g., activated carbon) that will, if needed, remove organic contaminants in the air stream before releasing it to the atmosphere. A brief description of these steps is provided below:

1)   Construction of Sedimentation Basins - Two sedimentation basins are planned for the collection of runoff from the cap. These basins will be formed by constructing a dike above the existing ground surface. No intrusive work or significant sources of exposure are expected during this period.

2)   Grading - To promote runoff into the sedimentation ponds, minor grading of the site will be required. Assumptions concerning duration, volume, and rate of soil handling are the same as those described for grading under the soil cover alternative and are summarized in Table 4.

3)   Cap Construction - The cap will be comprised of several layers including: a low permeability barrier material (e.g., clay), a venting layer (if necessary), and cover soil. No intrusive activities or significant sources of exposure are expected during the actual cap construction phase. The estimated duration of cap construction is 8 weeks.

4)   Miscellaneous Site Work - Various activities, such as seeding, grading noncontaminated edge areas, and fence construction will be required after completion of the cap. No intrusive work or significant sources of exposure are expected during this period.

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During the construction of the cap and after its completion, there are several sources of exposure that may contribute to risk. With the removal of the SVE system, vapor in the air-filled pore space previously removed by the SVE system will begin to diffuse upward through the less contaminated, overlying soil to the atmosphere. This passive diffusion process will continue to occur through the entire period of cap construction, until a relatively impermeable barrier (e.g., the clay layer of the cap) is completed. As a conservative estimate, it is assumed that passive diffusion emissions will occur during the entire period from removal of the SVE system until completion of the cap (estimated to be 90 days). In addition, of the four steps noted above, it is expected that emissions of volatile constituents in the soil will occur during soil moving activities associated with grading the site. Risks associated with emissions of volatile constituents from these sources (passive diffusion and grading) are considered in this report.

After completion of the cap, it is expected that, over time, volatile compounds in the soils beneath the cap will diffuse through the cap and be emitted to the atmosphere. The venting system will be used to limit this diffusion through the cap if there are indications that diffusion of these vapors presents an unreasonable health risk. It is assumed that a venting layer, if used, will have a 95 percent capture efficiency for vapors diffusing upwards. Post-implementation risks, therefore, may occur due to exposure to volatile compounds emitted through the cap and transported off-site. A summary of the potential sources of exposure associated with the capping alternative is presented in Table 6 at the end of this chapter.

D. Alternative 3 - Wet Soil Cover

The wet soil cover alternative is designed to provide containment for upward vapor transport of chemicals and a deterrent to direct contact with contaminated soils. The system is comprised of an infiltration blanket that introduces clean water that creates a nearly saturated soil layer overlying the former lagoon areas. Water will percolate through the soil cover into underlying lagoon area soils to minimize upward migration of contaminant vapors. This water will mix with the ground water and flow toward the existing french drain along the northern border of the site. Sump pumps within the french drain will remove the shallow ground water for treatment.

Prior to construction of the infiltration blanket, minor site preparation, including grading, will be performed to provide adequate drainage. As described in the soil cover and capping alternatives, soil handling activities associated with grading are estimated to be contained within the uppermost two feet of soil; therefore, very little disturbance of soils is expected. The methodology and assumptions (summarized in Table 4) for site grading

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described in the soil cover and capping alternatives are assumed to apply to this alternative also.

Sources of exposure associated with implementation of the wet soil cover alternative involve volatile emissions from: 1) passive diffusion between the removal of the SVE system and the completion of the cap; and 2) soil handling/moving activities associated with site preparation (grading). Because the wet soil cover is designed to inhibit the upward diffusion of volatile constituents through the soil column (as discussed in Appendix H), it is not expected that any volatile emissions from lagoon area soils will occur after implementation of this remedy. Direct contact exposure (soil ingestion and dermal contact) by a maintenance worker or trespasser, however, may occur. A summary of the potential sources of exposure associated with the wet soil cover alternative is presented in Table 6 at the end of this chapter.

E.   Alternative 4 - On-site LTTD

The on-site LTTD alternative involves excavating contaminated soils in the unsaturated zone, transferring excavated soil directly to a dump truck, transporting the soil across the site to an enclosed soil processing area, processing the soil in preparation for on-site treatment, and treating the soil in an LTTD system. The following sections describe the assumptions concerning: 1) the excavation process; 2) soil processing in the enclosure; and 3) soil treatment in the LTTD unit.

1.   Excavation Process

The excavation process will be performed in a series of cells. It is estimated that the average active excavation area (cell), on any given day, will be approximately 20 feet by 90 feet (1800 ft^2). Soil will be removed from the active cell in a series of lifts that will continue to the top of the saturated zone. Excavation will proceed onto an adjoining cell, following the same routine. Excavated cells will be backfilled, leaving an open buffer cell between the clean backfill cell and the contaminated active cell. During down time (e.g., at night), measures will be taken to minimize volatile emissions from the exposed areas.

Soil removed from the active excavation area will be transferred directly from the backhoe to a waiting dump truck. Volatile chemical emissions will occur, while the dump truck is being filled. The dump truck will transport the soil across the site to a centrally located, enclosed soil processing area.

In order to estimate the magnitude of emissions from the various soil handling

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processes associated with excavation, it is necessary to identify such factors as the volume of soil requiring excavation, the location and configuration of sources, and the duration of each activity. Assumptions used in the risk assessment concerning the implementation methodology for the on-site LTTD alternative are summarized in Table 5 and described below.

a. Estimation of Excavation Soil Volume

Contaminated soils in the unsaturated zone with total VOC concentrations exceeding 1,000 mg/kg will be excavated. Based on sampling performed during the course of the SVE system installation and implementation, it is unlikely that excavation will be required in the portion of the site referred to as the lower east lagoon area. The other areas of the site, however, including the lower west, upper west, and upper east lagoons will be excavated under this alternative. To estimate the volume of soil that will be excavated from these areas, ERM (personal communication, ERM 1994) developed contour maps of the saturated zone and estimated that 13,070 yd³ of unsaturated soil would require excavation. Of this total volume, 8,760 yd³ was estimated by ERM to be contained within the upper east, 3,980 yd³ in the upper west, and 330 yd³ in the lower west lagoon areas.

b. Location, Configuration, and Duration of Excavation Sources

The rate at which the soil excavation and handling process proceeds is based on such factors as the size of the excavator bucket, percent of boulders and cobbles, the feed rate of the screening and crushing units, and the LTTD processing rate. ERM estimates that the excavation rate will be 200 tons/day (personal communication, ERM 1994). Since *in-situ* soils at the site have an approximate density of 1.51 tons/yd³, this amounts to an excavation rate of approximately 132 yd³/day. Therefore, based on the total excavation volume of 13,070 yd³, it is estimated that the excavation process will require 99 days.

Over the active excavation area of 1800 ft² (167 m³), approximately two feet of soil will be excavated each day. Assuming six-inch lifts, the surface of the cell will be renewed four times per day (i.e., 7,200 seconds between soil disturbances over an eight-hour day). Soil removed from the active excavation area will be transferred directly to a waiting dump truck.

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TABLE 5	
Summary of Assumptions Associated with Excavation	
Parameter	**Value**
Excavation Rate, m³/sec	0.0042[a]

Exposed Surface Area, m²
    Excavation Area
    Truck Loading
	
	167[b]
	9.3[c]

Time Period Between Soil
Disturbances, seconds
    Excavation Area
    Dump Truck Loading
	
	7200[d]
	180[e]

Implementation Duration, days	99[f]

Fraction of Excavation Duration[g]:
    Lower West Lagoon Area
    Upper West Lagoon Area
    East Lagoon Area
	
	0.15
	0.25
	0.60

a - Based on excavation of 200 tons/day which is equal to a soil volume of 159 yd³ (200 tons/1.51 tons/yd³ x 1.2 bulking factor) over an 8-hour day (159 yd³/28,800 sec or 121.6 m³/28,800 sec).
b - Based on 20-foot x 90-foot excavation area.
c - Estimated area of dump truck bed (100 ft²).
d - Based on the assumption that the surface of the entire excavation pit will be disturbed once every two hours.
e - Based on a bucket capacity of 1-cubic yard and an excavation volume of 159 yd³ per 8-hour day (28,800 sec/159 loads).
f - Based on total excavation volume of 13,070 yd³
g - Based on the estimated distribution of soil volume between lagoons

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The dump truck is estimated to have a bed size of 100 ft^2.

It is estimated that handling of the soil during excavation will result in an increase in volume of 20 percent. Therefore, a bulking factor of 1.2 was applied to the volume of excavated soil. Assuming that the volume of the backhoe bucket is 1 yd^3, 159 loads of soil will be dumped into a dump truck over an eight-hour day (28,800 sec). Therefore, freshly excavated soil will, on average, be exposed to the atmosphere for 180 seconds (28,800 sec/159 loads). Filled dump trucks will transport the soil across the site to a centrally located, enclosed soil processing area. It is anticipated that volatile emissions will occur from the open bed of the dump truck during loading.

2. Soil Processing Enclosure

Within the enclosure, a number of different processes are expected to occur, including dumping the soil from the dump truck; removing and segregating boulders and cobbles from the excavated soil; and screening and crushing the soil to provide a uniform size fraction for LTTD treatment. Emission of volatile constituents in the contaminated soil within the enclosure may be significant because of the high degree of soil handling involved in soil processing, potentially resulting in a build-up of volatile constituents inside the enclosure. An air handling system will have to be designed to reduce concentrations within the enclosure to levels acceptable to workers. Air pollution control equipment associated with the air handling system for the enclosure will limit emissions to the atmosphere. Fugitive emissions from tears, openings, and seams between the enclosure and the ground surface will nevertheless occur.

3. LTTD Treatment Unit

Soil processed within the enclosure will be transferred to the LTTD treatment unit outside the enclosure via a feed hopper inside the enclosure. Processed soils will be treated by the LTTD and returned to the excavation pit as backfill. Volatile constituents in the soil will be removed by a counter current air stream in the LTTD unit. Contaminants will be removed from the air stream using an air pollution control system that circulates the air back through the unit. It is expected that only very minor fugitive emissions from the LTTD unit to the atmosphere will occur.

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excavation will proceed through a soil depth of 2 feet each day. Assuming that four lifts are used across the entire active excavation pit, the surface of the pit is renewed four times per day (i.e., 7,200 seconds between soil disturbances over an eight-hour day). Soil removed from the active excavation area will be transferred directly to a waiting dump truck. The dump truck is estimated to have a bed size of 100 ft².

It is estimated that handling of the soil during excavation will result in an increase in volume of 20 percent. Therefore, a bulking factor of 1.2 was applied to the volume of excavated soil. Assuming that the volume of the backhoe bucket is 1 yd³, 159 loads of soil will be dumped into a dump truck over an eight-hour day (28,800 sec). Therefore, freshly excavated soil will, on average, be exposed to the atmosphere for 180 seconds (28,800 sec/159 loads). Filled dump trucks will transport the soil across the site to an enclosed soil processing area located in the eastern portion of the site. It is anticipated that volatile emissions will occur from the open bed of the dump truck during loading.

Excavated soil will be processed within the enclosure in the same manner as required for LTTD treatment. After processing, the soil will be transferred to a roll-off container within the enclosure. Once full, the container will be covered and transported to an on-site rail loading facility for off-site transport by rail.

It is estimated that exposure to contaminants in site soils may occur during implementation of the off-site incineration/disposal alternative due to emissions during active excavation and dump truck loading, and emissions (fugitive and point source) from the soil processing enclosure.

After implementation of the remedy, DNAPL constituents present in bedrock beneath the site will diffuse upward through the clean backfill and will eventually be emitted to the atmosphere. Exposure to airborne contaminants emitted from DNAPL in the bedrock, therefore, may occur to a maintenance worker, on-site trespasser, or off-site resident. A two-foot soil cover will be placed over the lagoon area to limit direct contact exposure with soil by a maintenance worker or trespasser, although some soil contact may nevertheless occur. A summary of the potential sources of exposure associated with the off-site incineration/disposal alternative is presented in Table 6.

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	Potential Exposure Source	
TABLE 6 **Summary of Potential Sources of Exposure Associated with** **the Tyson's Site Remedial Alternatives**		
Alternative	**Implementation**	**Post-Implementation**

Soil Cover	Site Preparation (grading)
	    Off-Site Resident (Inh)
	
	Passive Diffusion
	    Off-Site Resident (Inh)
		Passive Diffusion
		    Off-Site Resident (Inh)
		    Maintenance Worker (Inh)
		    Trespasser (Inh)
		
		Direct Soil Contact
		    Maintenance Worker (Ing, Der)
		    Trespasser (Ing, Der)

Capping[a]	Site Preparation (grading)
	    Off-Site Resident (Inh)
	
	Passive Diffusion
	    Off-Site Resident (Inh)
		Passive Diffusion (through cap)
		    Off-Site Resident (Inh)
		    Maintenance Worker (Inh)
		    Trespasser (Inh)

Wet Soil Cover	Site Preparation (grading)
	    Off-Site Resident (Inh)
	
	Passive Diffusion
	    Off-Site Resident (Inh)
		Direct Soil Contact
		    Maintenance Worker (Ing, Der)
		    Trespasser (Ing, Der)

On-Site LTTD	Active Excavation and Soil Processing
	    Off-Site Resident (Inh)
		Passive Diffusion (DNAPL in bedrock[b])
		    Off-Site Resident (Inh)
		    Maintenance Worker (Inh)
		    Trespasser (Inh)
		
		Direct Soil Contact (residual)
		    Maintenance Worker (Ing, Der)
		    Trespasser (Ing, Der)

Off-Site
Incineration/
Disposal
	Active Excavation and Soil Processing
	    Off-Site Resident (Inh)
		Passive Diffusion (DNAPL in bedrock)
		    Off-Site Resident (Inh)
		    Maintenance Worker (Inh)
		    Trespasser (Inh)
		
		Direct Soil Contact
		    Maintenance Worker (Ing, Der)
		    Trespasser (Ing, Der)

NOTES:

a - Passive diffusion emissions due to DNAPL in bedrock were estimated to be more significant than emissions due to residual soil contamination after LTTD treatment.

Inh - Inhalation

Ing - Soil ingestion

Der - Dermal contact with soil

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FINAL DRAFT

V. ESTIMATION OF EXPOSURE DOSE

A. Introduction

Defining exposure to populations that may come in contact with contaminants at a site (referred to as exposure assessment) is an integral part of risk assessment. EPA has developed guidelines for conducting exposure assessments that were published in the May 29, 1992 Federal Register (FR 57: 22887-22938). The EPA guidelines recommend that exposure be estimated for both "central tendency" and "high-end" individuals within the exposed population. Central tendency exposure is based on typical exposure patterns and is intended to reflect the average or median within the exposed population. High-end exposure estimates are developed to include members of the exposed population that are in the upper end of the exposure distribution. Conceptually, the guidelines define the high end of the exposure distribution as within the upper ten percent of the exposure distribution, but not higher than the upper bound (i.e., not above the expected highest value in the true exposure distribution of the exposed population).

The central tendency and high-end exposure portions of the exposure distribution for the exposed population cannot be measured directly; therefore, they must be estimated. The measurement of the magnitude of exposure, referred to as the exposure dose, is estimated by combining exposure factors, reflecting activity and behavior patterns of the exposed population, with media concentrations. Exposure factors include, for example, inhalation rate, exposure duration, and exposure frequency and are generally specific to the exposed population.

Central tendency exposure is estimated by combining typical exposure factors that represent the median of the range of possible values for each factor. In doing so, exposure that approximates the median of the exposure distribution of the population is estimated. Superfund guidelines were used to characterize reasonable maximum exposure (RME), which are considered to be generally consistent with high-end exposure.

As noted previously, exposure was quantified for three exposure populations (exposure scenarios), including: off-site residents, who may be exposed to vapors emanating from the site; trespassing children, who may be exposed to vapors and soil while playing on-site; and on-site maintenance workers, who may be exposed to vapors and soil during routine

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visits to the site. The exposure populations, and the associated exposure pathways are shown in Table 3 (page 22). Each pathway is represented by several exposure factors which, as described above, were combined to estimate the exposure dose. Tabulated exposure doses for the pathways and populations considered in this assessment are provided in Appendix D.

B. Estimation of Exposure Dose

The EPA exposure assessment guidelines recommend that exposure be determined as an average daily dose (ADD) for chemicals with noncancer health effects and a lifetime average daily dose (LADD) for carcinogens. Therefore, the estimated dose is averaged over the period of exposure for chemicals with noncancer health effects and over an individual's lifetime for carcinogens. The period over which exposure occurs (referred to as the Averaging Time for noncarcinogens) is equal to the exposure duration (ED) for the specific exposure pathway expressed in days (i.e., ED x 365 days/year). A typical lifetime is assumed to be 70 years (25,550 days) based on EPA guidance (1990).

Three exposure pathways were considered in the analysis of exposure: inhalation, soil ingestion, and dermal contact with soil. The exposure dose for inhalation of vapors on- or off-site will be estimated using the following equation:

$$ADD = \frac{CA \times IR \times ET \times EF \times ED \times \dfrac{mg}{10^3 \, \mu g}}{BW \times AT}$$

where:

CA	=	concentration of chemical in air, $\mu g/m^3$
IR	=	inhalation rate, m^3/hr
ET	=	exposure time, hr/day
EF	=	exposure frequency, days/year
ED	=	exposure duration, years
BW	=	body weight, kilograms
AT	=	time over which the dose is averaged, days

For chemicals with carcinogenic health effects, the LADD was estimated using the equation above, but with the averaging time replaced by the number of days in a lifetime, LT.

Ingestion of contaminated soil on-site may occur when a maintenance worker of

trespassing child visits the site. The equation that was used to estimate exposure dose for ingestion of soil is as follows:

$$ADD = \frac{CS \times \left(\dfrac{10^{-6}kg}{mg}\right) \times IR \times CF \times EF \times ED}{BW \times AT}$$

where:

CS	=	chemical concentration in soil, mg/kg
IR	=	soil ingestion rate, mg/day
CF	=	contact fraction, unitless
EF	=	exposure frequency, days/year
ED	=	exposure duration, years
BW	=	body weight, kilograms
AT	=	time over which the dose is averaged, days

For chemicals with carcinogenic health effects, the LADD was estimated using the equation above, but with the averaging time replaced by the number of days in a lifetime, LT.

Dermal contact with contaminated soil on-site may occur when a maintenance worker or trespassing child visits the site. The following equation was used to estimate exposure dose for dermal contact with soil:

$$ADD = \frac{CS \times SA \times AF \times \left(\dfrac{10^{-6}kg}{mg}\right) \times ABS \times CF \times EF \times ED}{BW \times AT}$$

where:

CS	=	chemical concentration in soil, mg/kg
SA	=	skin surface area available for contact, cm^2
AF	=	soil to skin adherence factor, mg/cm^2-day
ABS	=	absorption factor, unitless
CF	=	contact fraction, unitless
EF	=	exposure frequency, days/year
ED	=	exposure duration, years

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BW = body weight, kilograms

AT = time over which the dose is averaged, days

For chemicals with carcinogenic health effects, the LADD was estimated using the equation above, but with the averaging time replaced by the number of days in a lifetime, LT.

Values used in the exposure dose equations are discussed in the following sections for each of the exposure populations.

1. Off-Site Resident

Exposure to off-site residents may occur during both the implementation of the remedial alternative and after the remedy has been completed. In both cases, exposure is largely limited to inhalation of vapors off-site.

a. Implementation

Residents who live in the vicinity of the site may be exposed to chemicals that volatilize from lagoon soils and are transported off-site during implementation of the remedial alternative. Table 7 presents the exposure assumptions that were used to estimate the exposure dose to off-site residents during implementation of the remedial alternative. The values that are unique to each of the alternatives are the exposure time and duration. Sources of exposure associated with activities such as excavation or soil handling are assumed to be limited to periods when the activity is conducted (i.e., 8 hr/day); it is assumed that controls necessary to prevent emissions during non-working hours will be utilized. Passive diffusion emissions, however, are assumed to occur continuously (i.e., 24 hrs/day). Therefore, the exposure times for active emission sources (e.g., excavation) and passive sources (e.g., diffusion) are 8 hr/day and 24 hr/day, respectively.

The exposure duration for each alternative (and individual components of the alternatives) was estimated based on the time periods to complete each remedy.

Values for the inhalation rate and body weight of an adult are the same for all remedial alternatives. The average and reasonable maximum inhalation rates that were used to estimate average and reasonable maximum exposure

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TABLE 7 Exposure Assumptions for Inhalation of Vapors by Adult Off-Site Resident (Implementation)		
Parameter	Excavation	Passive Diffusion
Chemical Concentration in Air, μg/m^3	Chemical Specific	
Inhalation Rate, m^3/hr	0.833/1.25[a]	
Exposure Time, hr/day	8[b]	24[b]
Exposure Duration, days	Remedy-Specific	
Body Weight, kg	70	
Averaging Time, days (noncarcinogens)	Remedy-Specific (equal to exposure duration)	
Lifetime, days (carcinogens)	25,550	

a - Values are estimates of average and reasonable maximum inhalation rates.
b - An exposure time of 24 hours/day was used for continuous sources (passive diffusion) and a value of 8 hours/day for sources limited to the work day (excavation/soil handling).

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doses are 0.833 m^3/hr and 1.25 m^3/hr, respectively. The body weight of an adult is estimated as 70 kilograms (USEPA 1990).

b.   Post-Implementation

The magnitude of exposure to an off-site resident after implementation of the remedy depends on several exposure parameters, as shown in Table 8. An inhalation rate of 0.833 m^3/hr (20 m^3/day) is recommended by EPA (1990) for adult residents. Exposure time and frequency of 24 hours/day and 350 days/year were used, based on EPA guidance (USEPA 1991b). Exposure duration is the total time over which exposure is expected to occur. EPA (1990) recommends typical and reasonable maximum values of 9 and 30 years, respectively, for adult residential exposure.

2.   Trespassing Child

The trespassing child scenario considers the risks to children in the 6 to 12 year-old age group, who may trespass and play on-site and be exposed to vapors emitted from lagoon soil. Direct contact exposure (ingestion and dermal contact) to uncovered contaminated soil is also considered in this scenario.

For each of the three exposure pathways, the exposure duration and frequency, and body weight are the same. The exposure duration is assumed to be six years, corresponding to the 6 to 12 year-old age range. The exposure frequency is based on the assumption that a child is more likely to play outside during warmer months (assumed on days when the temperature exceeds 60° F). Weather data from the Philadelphia weather station (NOAA 1985) indicate that the normal daily maximum temperature is above 60° F approximately 7 months/year (30 weeks). It is assumed that a child will trespass on the site 1 day/week, resulting in an exposure frequency of 30 days/year. It should be noted that this level of trespass is unlikely given the presence of a fence that will be maintained following remedy implementation.

The body weight of a 6 to 12 year old child is estimated to be 31 kg (USEPA 1990). The remaining exposure factors are generally specific to each exposure pathway and are discussed separately below.

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TABLE 8 Exposure Assumptions for Inhalation of Vapors by Adult Off-Site Resident (Post-Implementation)	
Parameter	**Value**
Chemical Concentration in Air, $\mu g/m^3$	Chemical Specific
Inhalation Rate, m^3/hr	0.833[a]
Exposure Time, hr/day	24
Exposure Frequency, days/yr	350
Exposure Duration, years	9/30[b]
Body Weight, kg	70
Averaging Time, days (noncarcinogens)	3,285/10,950[c]
Lifetime, days (carcinogens)	25,550

a - USEPA 1990
b - Values are for average and reasonable maximum exposure duration (USEPA 1990).
c - Values correspond to average and reasonable maximum exposure duration.

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a.   Inhalation of Vapors

Data on activity-specific inhalation rates for children have been compiled by EPA (1990). For the typical value, the inhalation rate for a 10 year-old child during light play of 1.0 m³/hour was used. The inhalation rate for moderate play of 3.2 m³/hour was used for the reasonable maximum value.

The amount of time that a child plays on the site directly affects the magnitude of exposure. It was assumed that typically, a child will spend 1 hr/day on-site. The values used in estimating the average and reasonable maximum exposure doses are presented in Table 9.

b.   Soil Ingestion

In estimating risks to children exposed to contaminated soil, EPA (1990) recommends a soil ingestion rate of between 100 mg/day and 200 mg/day. The lower and upper ends of this range were used for the average and reasonable maximum soil ingestion rates for the trespassing child scenario. It is estimated that on days when a child trespasses on-site, 25 percent of the total soil ingested during the day will be derived from the site; therefore, a contact fraction of 0.25 was estimated. The values used to estimate average and reasonable maximum exposure doses are presented in Table 10.

c.   Dermal Contact With Soil

The amount of skin surface available for contact is estimated based on the expected activities and the types of clothing worn during the period of exposure. For the typical area of skin exposed, it is assumed that exposure would primarily occur to the hands and forearms. Age-specific skin surface areas of these body parts derived from EPA (1990) guidance were summed to estimate a typical value of 1,330 cm².

Soil to skin adherence factor values of 0.2 mg/cm²-day and 1.0 mg/cm²-day are recommended by EPA (1992b) for typical and reasonable maximum values, respectively. The absorption factor, which represents the fraction of a specific chemical in contact with skin that will be absorbed through the skin is estimated to be 0.1 (10 percent), based on data compiled by EPA (1992b). It is estimated that 25 percent of total daily soil exposure will occur at the site; therefore, a contact fraction of 0.25 was estimated. The values used to estimate average and reasonable maximum exposure doses are

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TABLE 9 Exposure Assumptions for Inhalation of Vapors by On-Site Trespassing Child	
Parameter	**Value**
Chemical Concentration in Air, $\mu g/m^3$	Chemical Specific
Inhalation Rate, m^3/hr	1.0/3.2[a]
Exposure Time, hr/day	1
Exposure Frequency, days/yr	30
Exposure Duration, years	6
Body Weight, kg	31[b]
Averaging Time, days (noncarcinogens)	2,190
Lifetime, days (carcinogens)	25,550

a - Values are average and reasonable maximum inhalation rates based on USEPA 1990.
b - USEPA 1990

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TABLE 10
Exposure Assumptions for Ingestion of Soil by On-Site Trespassing Child

Parameter	Value
Chemical Concentration in Soil, mg/kg	Chemical Specific
Ingestion Rate, mg/day	100/200[a]
Contact Fraction, unitless	0.25
Exposure Frequency, days/yr	30
Exposure Duration, years	6
Body Weight, kg	31[b]
Averaging Time, days (noncarcinogens)	2,190
Lifetime, days (carcinogens)	25,550

a -   Values are average and reasonable maximum soil ingestion rates based on USEPA 1990.
b -   USEPA 1990

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presented in Table 11.

3. On-Site Maintenance Worker

The on-site maintenance worker scenario assumes that after completion of the remedy, a maintenance worker will visit the site on a regular basis. It is anticipated that future use of the site will include a ground water system that is part of the ground water remedy. It is assumed that a maintenance worker, therefore, will visit the site routinely to: maintain equipment (e.g., ground water system) and the vegetative cover. Exposure to chemicals in air and soil may occur during the routine visits.

a. Inhalation of Vapors

Average exposure factor values were identified for the parameters shown in Table 12. An inhalation rate of 0.833 m^3/hr (20 m^3/day) is based on EPA guidance (1990). An exposure time and frequency of 2 hr/day and 250 days/yr, respectively, were estimated based on the assumption that a maintenance worker will visit the site daily, generally for brief periods. For the average and reasonable maximum exposure duration, values of 5 and 25 years were estimated, respectively, based on Bureau of Labor statistics for the time period an individual remains at one job (USEPA 1990).

b. Soil Ingestion

A soil ingestion rate of 100 mg/day was used for the maintenance worker (EPA 1990). It is estimated that 25 percent of the maintenance worker's total daily soil exposure will occur at the site; therefore, a contact fraction of 0.25 was used. For the average and reasonable maximum exposure duration, values of 5 and 25 years were estimated, respectively, based on Bureau of Labor statistics for the time period an individual remains at one job (USEPA 1990). The values used to estimate average and reasonable maximum exposure doses are presented in Table 13.

c. Dermal Contact With Soil

The amount of skin surface available for contact (5,000 cm^2) is estimated based on EPA dermal exposure assessment guidance (USEPA 1992b). A soil to skin adherence factor value of 0.2 mg/cm^2-day is recommended by EPA (1992b). The absorption factor, which represents the

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TABLE 11 Exposure Assumptions for Dermal Contact with Soil by On-Site Trespassing Child	
Parameter	**Value**
Chemical Concentration in Soil, mg/kg	Chemical Specific
Adherence Factor, mg/cm^2-day	0.2/1.0[a]
Surface Area of Skin Exposed, cm^2	1330
Absorption Factor, unitless	0.1
Contact Fraction, unitless	0.25
Exposure Frequency, days/yr	30
Exposure Duration, years	6
Body Weight, kg	31[b]
Averaging Time, days (noncarcinogens)	2,190
Lifetime, days (carcinogens)	25,550
a - Values are average and reasonable maximum adherence factors based on USEPA 1992b.	

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TABLE 12 Exposure Assumptions for Inhalation of Vapors by On-Site Maintenance Worker	
Parameter	**Value**
Chemical Concentration in Air, $\mu g/m^3$	Chemical Specific
Inhalation Rate, m^3/hr	0.833
Exposure Time, hr/day	2
Exposure Frequency, days/yr	250
Exposure Duration, years	5/25[a]
Body Weight, kg	70
Averaging Time, days (noncarcinogens)	1,825/9,125
Lifetime, days (carcinogens)	25,550

a -   Values are average and reasonable exposure durations based on USEPA (1990).

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TABLE 13 Exposure Assumptions for Ingestion of Soil by On-Site Maintenance Worker	
Parameter	Value
Chemical Concentration in Soil, mg/kg	Chemical Specific
Ingestion Rate, mg/day	100[a]
Contact Fraction, unitless	0.25[b]
Exposure Frequency, days/yr	250
Exposure Duration, years	5/25[c]
Body Weight, kg	70
Averaging Time, days (noncarcinogens)	1,825/9125[d]
Lifetime, days (carcinogens)	25,550

a - USEPA 1990
b - Based on estimate that 25 percent of the maintenance worker's soil exposure occurs at the site.
c - Values are average and reasonable exposure durations based on USEPA (1990).
d - Values are based average and reasonable exposure durations.

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fraction of a specific chemical in contact with skin that will be absorbed through the skin is estimated to be 0.1 (10 percent), based on data compiled by EPA (1992b). It is estimated that 25 percent of total daily soil exposure will occur at the site; therefore, a contact fraction of 0.25 was estimated. The values used to estimate average and reasonable maximum exposure doses are presented in Table 14.

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TABLE 14	
Exposure Assumptions for Dermal Contact with Soil by On-Site Maintenance Worker	
Parameter	**Value**
Chemical Concentration in Soil, mg/kg	Chemical Specific
Adherence Factor, mg/cm^2-day	0.2
Surface Area of Skin Exposed, cm^2	5,000[a]
Contact Fraction, unitless	0.25[b]
Absorption Factor, unitless	0.1
Exposure Frequency, days/yr	250
Exposure Duration, years	5/25[c]
Body Weight, kg	70
Averaging Time, days (noncarcinogens)	1,825/9,125[d]
Lifetime, days (carcinogens)	25,550

a - USEPA 1992b
b - Based on estimate that 25 percent of the maintenance worker's soil exposure occurs at the site.
c - Values are average and reasonable exposure durations based on USEPA (1990).
d - Values are based average and reasonable exposure durations.

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VI. RISK CHARACTERIZATION

A. Introduction

Risk characterization is the final step of the risk assessment process. In this step, the toxicity values (i.e., SFs and RfDs) for the modeled chemicals are used in conjunction with the estimated exposure dose for each of the various exposure pathways to estimate quantitatively both carcinogenic and noncarcinogenic health risks. The methodology for deriving quantitative risk estimates is presented below.

B. Methodology for Quantitative Risk Estimation

1. Estimation of Cancer Risks

The numerical estimate of the excess lifetime cancer risk resulting from non-inhalation exposure to a specific carcinogenic chemical can be calculated by multiplying the lifetime average daily dose (LADD) by the SF, as follows:

$$Risk = LADD \times SF$$

where,

Risk	=	lifetime probability of developing cancer due to exposure to the chemical
LADD	=	lifetime average daily dose, mg/kg-day
SF	=	carcinogenic slope factor, $(mg/kg\text{-}day)^{-1}$

Total risks are estimated as the sum of the individual risk estimates.

2. Estimation of the Potential for Noncancer Effects

The numerical estimate of the potential for adverse noncancer effects resulting from exposure to noncarcinogens is derived in the following manner:

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$$\text{Potential for adverse effects} = \text{ADD/RfD}$$

where,

$$\text{ADD} = \text{average daily dose, mg/kg-day}$$
$$\text{RfD} = \text{reference dose, mg/kg-day}$$

The resulting ratio is referred to as the hazard quotient (HQ). If the HQ is less than or equal to one, it is assumed that the exposed population would not be affected. If the HQ is greater than one, there is an increased potential for noncancer effects to occur. A HQ that is greater than one should not be interpreted to mean that adverse effects will occur, because the uncertainty (safety) factors used in estimating the RfD and the conservative assumptions used in estimating the ADD would tend to overestimate exposure. As a rule, however, the greater the value of the HQ above one, the greater the likelihood of noncancer effects occurring.

The assessment of overall potential for noncancer effects posed by simultaneous exposure to multiple chemicals is conducted using the Hazard Index approach developed in USEPA's "Guidelines for the Health Risk Assessment of Chemical Mixtures" (USEPA 1986a) and described in USEPA's "Risk Assessment Guidance for Superfund" (USEPA 1989). As a first screening, the HQ values for individual chemicals associated with a given exposure pathway are summed to provide an indication of the potential for noncancer effects posed by multiple chemical exposure. The sum of the HQ values for individual chemicals is referred to as the Hazard Index (HI). The HI approach assumes that multiple sub-threshold exposures could result in an adverse effect and that a reasonable criterion for evaluating the potential adverse effects is the sum of the hazard quotients (USEPA 1986a).

C.   Estimates of Excess Cancer Risk and Potential for Noncancer Health Effects

Tables 15 to 21 summarize the average and reasonable maximum lifetime excess cancer risk estimates for the chemicals of potential concern for three exposure populations: off-site residents (implementation and post-implementation risks); maintenance worker (post-implementation risks); and trespassing child (post-implementation risks). Tables 22 to 28 summarize the average and reasonable maximum hazard quotients for the chemicals of potential concern with noncancer health effects considered in this assessment. In general, the estimated hazard quotients for all exposure populations and pathways were significantly

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TABLE 15 Lifetime Cancer Risks for Off-Site Resident Due to Inhalation Exposure						
	Remedial Alternative					
Chemical	**Soil Cover**	**Capping without Venting**	**Capping with Venting**	**Wet Soil Cover**	**On-Site LTTD**	**Off-Site Incineration/ Disposal**
Implementation Cancer Risk						
Benzene						
Average	3×10^{-9}	3×10^{-9}	3×10^{-9}	3×10^{-9}	3×10^{-8}	3×10^{-8}
RME	9×10^{-9}	1×10^{-8}	1×10^{-8}	1×10^{-8}	9×10^{-8}	9×10^{-8}
Tetrachloroethene						
Average	7×10^{-10}	8×10^{-10}	8×10^{-10}	8×10^{-10}	6×10^{-9}	6×10^{-9}
RME	1×10^{-9}	1×10^{-9}	1×10^{-9}	2×10^{-9}	1×10^{-8}	1×10^{-8}
Trichloroethene						
Average	5×10^{-10}	6×10^{-10}	6×10^{-10}	6×10^{-10}	7×10^{-9}	7×10^{-9}
RME	2×10^{-9}	2×10^{-9}	2×10^{-9}	2×10^{-9}	2×10^{-8}	2×10^{-8}
1,2,3-Trichloropropane						
Average	1×10^{-7}	1×10^{-7}	1×10^{-7}	1×10^{-7}	2×10^{-5}	2×10^{-5}
RME	2×10^{-7}	2×10^{-7}	2×10^{-7}	2×10^{-7}	4×10^{-5}	4×10^{-5}
Post-Implementation Cancer Risk						
Benzene						
Average	2×10^{-8}	1×10^{-10}	7×10^{-12}	NA	1×10^{-8}	1×10^{-8}
RME	7×10^{-8}	5×10^{-10}	2×10^{-11}		4×10^{-8}	4×10^{-8}
Tetrachloroethene						
Average	3×10^{-9}	9×10^{-12}	5×10^{-13}	NA	2×10^{-9}	2×10^{-9}
RME	1×10^{-8}	3×10^{-11}	2×10^{-12}		6×10^{-9}	6×10^{-9}
Trichloroethene						
Average	3×10^{-9}	1×10^{-11}	6×10^{-13}	NA	2×10^{-9}	2×10^{-9}
RME	1×10^{-8}	4×10^{-11}	2×10^{-12}		6×10^{-9}	6×10^{-9}
1,2,3-Trichloropropane						
Average	1×10^{-5}	1×10^{-6}	7×10^{-8}	NA	7×10^{-6}	7×10^{-6}
RME	3×10^{-5}	5×10^{-6}	2×10^{-7}		2×10^{-5}	2×10^{-5}
Total Cancer Risk[a]						
Average	1×10^{-5}	2×10^{-6}	2×10^{-7}	1×10^{-7}	3×10^{-5}	3×10^{-5}
RME	3×10^{-5}	5×10^{-6}	4×10^{-7}	2×10^{-7}	6×10^{-5}	6×10^{-5}

NA - Not applicable; significant emissions are not anticipated.
a - Sum of implementation and post-implementation risks.

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TABLE 16						
Lifetime Cancer Risk for Maintenance Worker Due to Inhalation Exposure On-Site						
Chemical	Remedial Alternative					
	Soil Cover	Capping without Venting	Capping with Venting	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation Cancer Risk						
Benzene						
Average	4×10^{-8}	3×10^{-10}	1×10^{-11}	NA	2×10^{-8}	2×10^{-8}
RME	2×10^{-7}	1×10^{-9}	7×10^{-11}		1×10^{-7}	1×10^{-7}
Tetrachloroethene						
Average	4×10^{-9}	1×10^{-11}	6×10^{-13}	NA	3×10^{-9}	3×10^{-9}
RME	2×10^{-8}	6×10^{-11}	3×10^{-12}		1×10^{-8}	1×10^{-8}
Trichloroethene						
Average	6×10^{-9}	3×10^{-11}	1×10^{-12}	NA	4×10^{-9}	4×10^{-9}
RME	3×10^{-8}	1×10^{-10}	6×10^{-12}		2×10^{-8}	2×10^{-8}
1,2,3-Trichloropropane						
Average	2×10^{-5}	2×10^{-6}	1×10^{-7}	NA	1×10^{-5}	1×10^{-5}
RME	8×10^{-5}	1×10^{-5}	6×10^{-7}		6×10^{-5}	6×10^{-5}
NA - Not applicable; significant emissions are not anticipated.						

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	Remedial Alternative				
Chemical	**Soil Cover**	**Capping[a]**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**
Post-Implementation Cancer Risk					
Benzene					
Average	6×10^{-12}	NA	6×10^{-12}	6×10^{-13}	1×10^{-13}
RME	5×10^{-11}		5×10^{-11}	8×10^{-12}	8×10^{-13}
Tetrachloroethene					
Average	3×10^{-11}	NA	3×10^{-11}	3×10^{-10}	2×10^{-13}
RME	3×10^{-10}		3×10^{-10}	3×10^{-9}	1×10^{-12}
Trichloroethene					
Average	2×10^{-12}	NA	2×10^{-12}	5×10^{-13}	5×10^{-14}
RME	2×10^{-11}		2×10^{-11}	3×10^{-12}	3×10^{-13}
1,2,3-Trichloropropane					
Average	2×10^{-8}	NA	2×10^{-8}	4×10^{-7}	3×10^{-10}
RME	2×10^{-7}		2×10^{-7}	4×10^{-6}	3×10^{-9}

TABLE 17
Lifetime Cancer Risk for Maintenance Worker Due to
On-Site Soil Ingestion

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 18 Lifetime Cancer Risk for Maintenance Worker Due to On-Site Dermal Contact with Soil					
Chemical	**Remedial Alternative**				
	Soil Cover	**Capping[a]**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**
Post-Implementation Cancer Risk					
Benzene					
Average	6×10^{-12}	NA	6×10^{-12}	7×10^{-13}	1×10^{-13}
RME	5×10^{-11}		5×10^{-11}	8×10^{-12}	8×10^{-13}
Tetrachloroethene					
Average	3×10^{-11}	NA	3×10^{-11}	3×10^{-10}	2×10^{-13}
RME	3×10^{-10}		3×10^{-10}	3×10^{-9}	1×10^{-12}
Trichloroethene					
Average	2×10^{-12}	NA	2×10^{-12}	5×10^{-13}	5×10^{-14}
RME	2×10^{-11}		2×10^{-11}	3×10^{-12}	3×10^{-13}
1,2,3-Trichloropropane					
Average	2×10^{-8}	NA	2×10^{-8}	4×10^{-7}	3×10^{-10}
RME	2×10^{-7}		2×10^{-7}	4×10^{-6}	3×10^{-9}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 19 Lifetime Cancer Risk for Trespassing Child Due to Inhalation Exposure On-Site						
	Remedial Alternative					
Chemical	**Soil Cover**	**Capping without Venting**	**Capping with Venting**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**
Post-Implementation Cancer Risk						
Benzene						
Average	7×10^{-9}	5×10^{-11}	3×10^{-12}	NA	5×10^{-9}	5×10^{-9}
RME	3×10^{-8}	2×10^{-10}	9×10^{-12}		2×10^{-8}	2×10^{-8}
Tetrachloroethene						
Average	8×10^{-10}	2×10^{-12}	1×10^{-13}	NA	5×10^{-10}	5×10^{-10}
RME	2×10^{-9}	7×10^{-12}	3×10^{-13}		2×10^{-9}	2×10^{-9}
Trichloroethene						
Average	1×10^{-9}	5×10^{-12}	3×10^{-13}	NA	8×10^{-10}	8×10^{-10}
RME	4×10^{-9}	2×10^{-11}	8×10^{-13}		3×10^{-9}	3×10^{-9}
1,2,3-Trichloropropane						
Average	3×10^{-6}	5×10^{-7}	2×10^{-8}	NA	2×10^{-6}	2×10^{-6}
RME	1×10^{-5}	1×10^{-6}	7×10^{-8}		7×10^{-6}	7×10^{-6}
NA - Not applicable; significant emissions are not anticipated.						

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TABLE 20 Lifetime Cancer Risk for Trespassing Child Due to On-Site Soil Ingestion					
	Remedial Alternative				
Chemical	**Soil Cover**	**Capping[a]**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**
Post-Implementation Cancer Risk					
Benzene					
Average	2×10^{-12}	NA	2×10^{-12}	2×10^{-13}	4×10^{-14}
RME	6×10^{-12}		6×10^{-12}	1×10^{-12}	1×10^{-13}
Tetrachloroethene					
Average	9×10^{-12}	NA	9×10^{-12}	9×10^{-11}	7×10^{-14}
RME	4×10^{-11}		4×10^{-11}	4×10^{-10}	2×10^{-13}
Trichloroethene					
Average	7×10^{-13}	NA	7×10^{-13}	2×10^{-13}	2×10^{-14}
RME	2×10^{-12}		2×10^{-12}	4×10^{-13}	4×10^{-14}
1,2,3-Trichloropropane					
Average	6×10^{-9}	NA	6×10^{-9}	1×10^{-7}	9×10^{-11}
RME	2×10^{-8}		2×10^{-8}	6×10^{-7}	4×10^{-10}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 21 Lifetime Cancer Risk for Trespassing Child Due to On-Site Dermal Contact with Soil					
Chemical	**Remedial Alternative**				
	Soil Cover	Capping[a]	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation Cancer Risk					
Benzene					
Average	5×10^{-13}	NA	5×10^{-13}	6×10^{-14}	1×10^{-14}
RME	4×10^{-12}		4×10^{-12}	7×10^{-13}	7×10^{-14}
Tetrachloroethene					
Average	2×10^{-12}	NA	2×10^{-12}	2×10^{-11}	2×10^{-14}
RME	3×10^{-11}		3×10^{-11}	3×10^{-10}	1×10^{-13}
Trichloroethene					
Average	2×10^{-13}	NA	2×10^{-13}	4×10^{-14}	4×10^{-15}
RME	2×10^{-12}		2×10^{-12}	3×10^{-13}	2×10^{-14}
1,2,3-Trichloropropane					
Average	2×10^{-9}	NA	2×10^{-9}	3×10^{-8}	2×10^{-11}
RME	2×10^{-8}		2×10^{-8}	4×10^{-7}	3×10^{-10}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 22 **Potential for Noncancer Health Effects (Hazard Quotient) for Off-Site Resident** **Due to Inhalation Exposure**						

Chemical	Remedial Alternative					
	Soil Cover	Capping without Venting	Capping with Venting	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Implementation						
Ethylbenzene						
Average	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-3}	2×10^{-3}
RME	8×10^{-4}	8×10^{-4}	8×10^{-4}	8×10^{-4}	5×10^{-3}	4×10^{-3}
Toluene						
Average	6×10^{-4}	6×10^{-4}	6×10^{-4}	7×10^{-4}	1×10^{-2}	1×10^{-2}
RME	2×10^{-3}	2×10^{-3}	2×10^{-3}	2×10^{-3}	2×10^{-2}	2×10^{-2}
Tetrachloroethene						
Average	2×10^{-2}	2×10^{-2}	2×10^{-2}	1×10^{-2}	8×10^{-2}	8×10^{-2}
RME	3×10^{-2}	3×10^{-2}	3×10^{-2}	4×10^{-2}	2×10^{-1}	2×10^{-1}
1,2,3-Trichloropropane						
Average	3×10^{-2}	3×10^{-2}	3×10^{-2}	3×10^{-2}	1×10^{-1}	1×10^{-1}
RME	6×10^{-2}	6×10^{-2}	6×10^{-2}	6×10^{-2}	2×10^{-1}	2×10^{-1}
Xylenes						
Average	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	7×10^{-4}	7×10^{-4}
RME	3×10^{-4}	3×10^{-4}	3×10^{-4}	3×10^{-4}	1×10^{-3}	1×10^{-3}
Post-Implementation						
Ethylbenzene						
Average	5×10^{-5}	2×10^{-7}	1×10^{-8}	NA	4×10^{-5}	4×10^{-5}
RME	5×10^{-5}	2×10^{-7}	1×10^{-8}		4×10^{-5}	4×10^{-5}
Toluene						
Average	4×10^{-4}	3×10^{-6}	1×10^{-7}	NA	3×10^{-4}	3×10^{-4}
RME	4×10^{-4}	3×10^{-6}	1×10^{-7}		3×10^{-4}	3×10^{-4}
Tetrachloroethene						
Average	1×10^{-3}	4×10^{-6}	2×10^{-7}	NA	7×10^{-4}	7×10^{-4}
RME	1×10^{-3}	4×10^{-6}	2×10^{-7}		7×10^{-4}	7×10^{-4}
1,2,3-Trichloropropane						
Average	2×10^{-3}	3×10^{-4}	1×10^{-5}	NA	1×10^{-3}	1×10^{-3}
RME	2×10^{-3}	3×10^{-4}	1×10^{-5}		1×10^{-3}	1×10^{-3}
Xylenes						
Average	4×10^{-5}	3×10^{-7}	1×10^{-8}	NA	3×10^{-5}	3×10^{-5}
RME	4×10^{-5}	3×10^{-7}	1×10^{-8}		3×10^{-5}	3×10^{-5}
NA - Not applicable; significant exposure is not anticipated.						

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	Remedial Alternative					
Chemical	**Soil Cover**	**Capping without Venting**	**Capping with Venting**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**

TABLE 23
Potential for Noncancer Health Effects (Hazard Quotient) for Maintenance Worker Due to Inhalation Exposure On-Site

Post-Implementation						
Ethylbenzene						
Average	2×10^{-4}	7×10^{-7}	3×10^{-8}	NA	1×10^{-4}	1×10^{-4}
RME	2×10^{-4}	7×10^{-7}	3×10^{-8}		1×10^{-4}	1×10^{-4}
Toluene						
Average	2×10^{-3}	1×10^{-5}	6×10^{-7}	NA	1×10^{-3}	1×10^{-3}
RME	2×10^{-3}	1×10^{-5}	6×10^{-7}		1×10^{-3}	1×10^{-3}
Tetrachloroethene						
Average	3×10^{-3}	8×10^{-6}	4×10^{-7}	NA	2×10^{-3}	2×10^{-3}
RME	3×10^{-3}	8×10^{-6}	4×10^{-7}		2×10^{-3}	2×10^{-3}
1,2,3-Trichloropropane						
Average	6×10^{-3}	8×10^{-4}	4×10^{-5}	NA	4×10^{-3}	4×10^{-3}
RME	6×10^{-3}	8×10^{-4}	4×10^{-5}		4×10^{-3}	4×10^{-3}
Xylenes						
Average	1×10^{-4}	1×10^{-6}	5×10^{-8}	NA	9×10^{-5}	9×10^{-5}
RME	1×10^{-4}	1×10^{-6}	5×10^{-8}		9×10^{-5}	9×10^{-5}

NA - Not applicable; significant exposure is not anticipated.

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TABLE 24					
Potential for Noncancer Health Effects (Hazard Quotient) for Maintenance Worker Due to On-Site Soil Ingestion					

Chemical	Remedial Alternative				
	Soil Cover	Capping[a]	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation					
Ethylbenzene					
Average	5×10^{-8}	NA	5×10^{-8}	3×10^{-6}	6×10^{-10}
RME	9×10^{-8}		9×10^{-8}	7×10^{-6}	7×10^{-10}
Toluene					
Average	2×10^{-8}	NA	2×10^{-8}	9×10^{-7}	3×10^{-10}
RME	3×10^{-8}		3×10^{-8}	3×10^{-6}	4×10^{-10}
Tetrachloroethene					
Average	7×10^{-7}	NA	7×10^{-7}	7×10^{-6}	6×10^{-9}
RME	2×10^{-6}		2×10^{-6}	2×10^{-5}	7×10^{-9}
1,2,3-Trichloropropane					
Average	6×10^{-6}	NA	6×10^{-6}	1×10^{-4}	9×10^{-8}
RME	1×10^{-5}		1×10^{-5}	3×10^{-4}	2×10^{-7}
Xylenes					
Average	3×10^{-8}	NA	3×10^{-8}	1×10^{-6}	3×10^{-11}
RME	5×10^{-8}		5×10^{-8}	3×10^{-6}	4×10^{-11}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 25					
Potential for Noncancer Health Effects (Hazard Quotient) for Maintenance Worker Due to On-Site Dermal Contact with Soil					
Chemical	**Remedial Alternative**				
	Soil Cover	**Capping[a]**	**Wet Soil Cover**	**On-site LTTD**	**Off-Site Incineration/ Disposal**
Post-Implementation					
Ethylbenzene					
Average	5×10^{-8}	NA	5×10^{-8}	3×10^{-6}	6×10^{-10}
RME	9×10^{-8}		9×10^{-8}	7×10^{-6}	7×10^{-10}
Toluene					
Average	2×10^{-8}	NA	2×10^{-8}	9×10^{-7}	3×10^{-10}
RME	3×10^{-8}		3×10^{-8}	3×10^{-6}	4×10^{-10}
Tetrachloroethene					
Average	7×10^{-7}	NA	7×10^{-7}	7×10^{-6}	6×10^{-9}
RME	2×10^{-6}		2×10^{-6}	2×10^{-5}	7×10^{-9}
1,2,3-Trichloropropane					
Average	6×10^{-6}	NA	6×10^{-6}	1×10^{-4}	9×10^{-8}
RME	1×10^{-5}		1×10^{-5}	3×10^{-4}	2×10^{-7}
Xylenes					
Average	3×10^{-8}	NA	3×10^{-8}	1×10^{-6}	3×10^{-11}
RME	5×10^{-8}		5×10^{-8}	3×10^{-6}	4×10^{-11}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 26
Potential for Noncancer Health Effects (Hazard Quotient) for Trespassing Child Due to Inhalation Exposure On-Site

Chemical	Remedial Alternative					
	Soil Cover	Capping without Venting	Capping with Venting	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation						
Ethylbenzene						
Average	3×10^{-5}	1×10^{-7}	6×10^{-9}	NA	2×10^{-5}	2×10^{-5}
RME	8×10^{-5}	4×10^{-7}	2×10^{-8}		6×10^{-5}	6×10^{-5}
Toluene						
Average	3×10^{-4}	2×10^{-6}	9×10^{-8}	NA	2×10^{-4}	2×10^{-4}
RME	8×10^{-4}	6×10^{-6}	3×10^{-7}		6×10^{-4}	6×10^{-4}
Tetrachloroethene						
Average	4×10^{-4}	1×10^{-6}	6×10^{-8}	NA	3×10^{-4}	3×10^{-4}
RME	1×10^{-3}	4×10^{-6}	2×10^{-7}		1×10^{-3}	1×10^{-3}
1,2,3-Trichloropropane						
Average	9×10^{-4}	1×10^{-4}	6×10^{-6}	NA	7×10^{-4}	7×10^{-4}
RME	3×10^{-3}	4×10^{-4}	2×10^{-5}		2×10^{-3}	2×10^{-3}
Xylenes						
Average	2×10^{-5}	2×10^{-7}	8×10^{-9}	NA	2×10^{-5}	2×10^{-5}
RME	6×10^{-5}	5×10^{-7}	3×10^{-8}		5×10^{-5}	5×10^{-5}

NA - Not applicable; significant exposure is not anticipated.

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TABLE 27 Potential for Noncancer Health Effects (Hazard Quotient) for Trespassing Child Due to On-Site Soil Ingestion					
Chemical	**Remedial Alternative**				
	Soil Cover	Capping[a]	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation					
Ethylbenzene					
Average	1×10^{-8}	NA	1×10^{-8}	7×10^{-7}	2×10^{-10}
RME	5×10^{-8}		5×10^{-8}	4×10^{-6}	4×10^{-10}
Toluene					
Average	5×10^{-9}	NA	5×10^{-9}	2×10^{-7}	8×10^{-11}
RME	2×10^{-8}		2×10^{-8}	1×10^{-6}	2×10^{-10}
Tetrachloroethene					
Average	2×10^{-7}	NA	2×10^{-7}	2×10^{-6}	2×10^{-9}
RME	9×10^{-7}		9×10^{-7}	1×10^{-5}	4×10^{-9}
1,2,3-Trichloropropane					
Average	2×10^{-6}	NA	2×10^{-6}	3×10^{-5}	2×10^{-8}
RME	7×10^{-6}		7×10^{-6}	2×10^{-4}	1×10^{-7}
Xylenes					
Average	7×10^{-9}	NA	7×10^{-9}	3×10^{-7}	8×10^{-12}
RME	2×10^{-8}		2×10^{-8}	1×10^{-6}	2×10^{-11}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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TABLE 28 Potential for Noncancer Health Effects (Hazard Quotient) for Trespassing Child Due to On-Site Dermal Contact with Soil					
Chemical	**Remedial Alternative**				
	Soil Cover	Capping[a]	Wet Soil Cover	On-site LTTD	Off-Site Incineration/ Disposal
Post-Implementation					
Ethylbenzene					
Average	4×10^{-9}	NA	4×10^{-9}	2×10^{-7}	4×10^{-11}
RME	3×10^{-8}		3×10^{-8}	3×10^{-6}	3×10^{-10}
Toluene					
Average	1×10^{-9}	NA	1×10^{-9}	6×10^{-8}	2×10^{-11}
RME	1×10^{-8}		1×10^{-8}	9×10^{-7}	1×10^{-10}
Tetrachloroethene					
Average	5×10^{-8}	NA	5×10^{-8}	5×10^{-7}	4×10^{-10}
RME	6×10^{-7}		6×10^{-7}	7×10^{-6}	3×10^{-9}
1,2,3-Trichloropropane					
Average	4×10^{-7}	NA	4×10^{-7}	9×10^{-6}	6×10^{-9}
RME	4×10^{-6}		4×10^{-6}	1×10^{-4}	8×10^{-8}
Xylenes					
Average	2×10^{-9}	NA	2×10^{-9}	7×10^{-8}	2×10^{-12}
RME	2×10^{-8}		2×10^{-8}	9×10^{-7}	1×10^{-11}

NA - Not applicable; significant exposure is not anticipated.
a - Includes both capping with and without a venting system.

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below one for all remedial alternatives. Therefore, the potential for noncancer health effects due to exposure to chemicals of potential concern was not considered significant. Lifetime cancer risk estimates are discussed in the following sections.

1. Off-Site Resident - Implementation

This exposure scenario considers exposure to an adult off-site resident located adjacent to the western edge of the site who is exposed to vapors emitted from the site during implementation of the remedial alternative. Lifetime cancer risk estimates for this scenario for each of the remedial alternatives are summarized in Table 15.

Lifetime cancer risks for three of the four carcinogenic chemicals of potential concern (benzene, PCE, and TCE) are significantly below 1×10^{-6} for all of the remedial alternatives. Lifetime cancer risks associated with inhalation to TCP exceed 1×10^{-5} for the on-site LTTD and the off-site incineration/disposal alternatives, primarily due to the invasive soil excavation activities associated with each of these remedies.

2. Off-Site Resident - Post-Implementation

This exposure scenario considers inhalation exposure to off-site residents after completion of the remedial alternative. Table 15 summarizes the lifetime cancer risks to off-site residents exposed to chemicals of potential concern emanating from the site. Total inhalation cancer risk estimates exceed 1×10^{-6} for all alternatives considered, except capping without venting under the average exposure and capping with venting under both average and reasonable maximum exposure. All alternatives exceed a total cancer risk of 1×10^{-6} under reasonable maximum exposure with the exception of capping with venting alternative.

The on-site LTTD and off-site incineration/disposal alternatives pose significant risks to off-site residents due to the upward diffusion of TCP, a constituent of DNAPL present in bedrock underlying the site. As evident from the risk estimates in Table 15, capping provides a more effective barrier to vapor migration than the soil cover. Post-implementation cancer risks associated with the wet soil cover alternative are insignificant. It is assumed that the downward percolation of water will limit upward vapor diffusion to insignificant levels.

3. Maintenance Worker - Post-Implementation

Exposure to a maintenance worker who visits the site routinely to service

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equipment or maintain the site is evaluated in this scenario for the post-implementation period. Average and reasonable maximum lifetime cancer risks due to inhalation, soil ingestion, and dermal contact exposure were estimated for the maintenance worker, and are summarized in Tables 16, 17, and 18, respectively. Cancer risks associated with benzene, PCE, and TCE exposure were not estimated to be significant for either exposure pathway for any of the remedial alternatives.

Inhalation TCP cancer risks (Table 16) for the maintenance worker are in the range of 1×10^{-6} to 1×10^{-4} or less for all alternatives. With the exception of the wet soil cover and capping with venting, the average and reasonable maximum estimated TCP cancer risk estimates for all alternatives exceed 1×10^{-6}.

Although highly unlikely, soil ingestion and dermal contact with soil lifetime cancer risks were estimated (Tables 17 and 18) for the maintenance worker for the soil cover, wet soil cover, and on-site LTTD alternatives. Lifetime cancer risk estimates for the on-site LTTD alternative reflect the residual TCP remaining in backfilled soil after LTTD treatment. Soil ingestion cancer risk estimates associated with the soil cover and wet soil cover alternatives are based on the assumption that a fraction of the low contaminated surficial soil at the site is not covered by a soil cover (a soil cover or cap is included in each of the five alternative designs). With the exception of the on-site LTTD alternative, soil ingestion and dermal contact cancer risks were not significant, as shown in Tables 17 and 18.

4.   Trespasser - Post-Implementation

Exposure to a child trespassing on-site is evaluated in this scenario for the post-implementation period. Average and reasonable maximum lifetime cancer risks due to inhalation, soil ingestion, and dermal contact exposure were estimated for the trespasser, and are summarized in Tables 19, 20, and 21, respectively. Cancer risks associated with benzene, PCE, and TCE exposure were not estimated to be significant by any of the exposure pathways or remedial alternatives. In addition, soil ingestion and dermal contact with soil were not estimated to result in significant lifetime cancer risks for any of the remedial alternatives.

For the soil cover, on-site LTTD, and off-site incineration/disposal alternatives, inhalation cancer risks due to exposure to TCP were estimated to be in the range of 1×10^{-6} to 1×10^{-5}, as indicated in Table 19. Neither of the capping alternatives nor the wet soil cover alternative were estimated to pose significant risks to a trespasser due to inhalation of TCP.

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VII. OTHER CONCERNS ASSOCIATED WITH REMEDIATION ACTIVITIES

A.   Introduction

Under the current excavation scenario, excavation of contaminated soils at the Tyson's Site is expected to occur through a series of steps, including active excavation with a backhoe, transfer of the soil to a dump truck, transport across the site, and soil processing (i.e., boulder separation) within an enclosure. Activities within the enclosure prior to treatment or disposal will include unloading of the dump truck, transfer of soil onto a vibrating grizzly using a front-end loader, separation of boulders and cobbles from soil, and transfer of soil to roll-off containers using a front-end loader.

During the portions of the excavation process that are conducted outside the enclosure, such as the active excavation, soil loading, and on-site transport, the potential exists for workers to be exposed to contaminants in soil. It is expected that personal protection equipment (PPE) will be required for these workers, but that natural dispersion of contaminants in the atmosphere will effectively dilute airborne contaminant concentrations in the work area. Within the enclosure, however, potential risks due to chemical exposure and accidents are greatly increased. Although PPE will minimize exposure to workers in the enclosure, working conditions within a confined space are likely to create an increased risk of accident or injury. Also, the PPE required will itself create additional hazards. It is anticipated that workers within the enclosure may experience any of the following risks during implementation of the excavation remedy:

- Exposure to elevated temperatures and the potential for heat stress;
- Accidents involving heavy equipment because of space limitations;
- Accidents that result in loss of PPE and potentially acute exposures to high concentrations of contaminant vapors;
- Injuries, possibly serious, caused by increased difficulties in communication, mobility, and visibility associated with the use of PPE; and,
- Hearing impairment because of high noise levels within the enclosure.

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Since there are limited quantitative data available to estimate accident frequency and consequences, a qualitative discussion of the risk of accidents is provided in the following sections. In addition, a discussion of the potential for acute health effects resulting from accidental exposure to contaminated air within the enclosure is provided, and aesthetic issues, such as odor impacts, have also been considered.

B.   Hazards to Workers Within the Enclosure

To minimize the potential for exposures to toxic materials, workers are generally required to wear some form of PPE during remediation activities. Levels of PPE (i.e., Levels A, B, C, and D) are used to specify the required ensemble of individual components used to protect workers from site-specific chemical hazards. For example, Level A includes a fully encapsulated, chemical-resistant suit with an attached breathing apparatus that provides the highest level of respiratory, skin, and eye protection. The lower levels of PPE provide varying degrees of respiratory and direct contact protection. Based on the type of conditions expected within the enclosure at the Tyson's Site, it is likely that Level B protection will be required.

Although the use of Level B PPE will virtually eliminate exposure to chemicals during routine activities within the enclosure, its use can pose significant worker hazards, such as reduced or impaired mobility, communication and visibility, heat stress, and physical stress. In addition, because of the potential for significantly elevated chemical concentrations within the enclosure, accidental exposure (e.g., from torn or impaired protective equipment) could result in high levels of exposure, albeit for a brief period of time.

1.   Heat Stress

Heat stress is the total heat load imposed on the body from both metabolic and external sources. In its early stages, heat stress causes rashes, drowsiness, cramps, and discomfort, threatening the individual and other workers if accidents should result. In more severe cases, heat stroke and death can occur. Heat stress is possible, under certain conditions, with any level of PPE. With higher levels of protection, however, the risk of heat stress increases due to difficulty in regulating body temperature within an encapsulated suit or breathing apparatus.

The inherent awkwardness of encapsulated suits during movement increases the metabolic cost of even simple tasks. Because encapsulated suits are impervious to vapor flow, convection, and radiative heat transfers, heat and water vapor (sweat) produced by the worker's body are trapped within the suit. As the air within the suit

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becomes saturated with water vapor, the evaporation of sweat is limited. During high thermal activities, humans rely primarily on sweat evaporation for cooling purposes. Investigators (Rogan 1968) reported a 27 to 80 percent reduction in work efficiency due to lack of ventilation in PPE suits. It has also been shown that workers commit more unsafe acts as temperatures and PPE levels increase (Ramsey et al. 1983).

Temperature data recorded at the Philadelphia International Airport (NOAA 1985) indicate that the normal daily maximum temperature exceeds 70° Fahrenheit for at least five months of the year (May through September) and reaches a normal daily maximum of approximately 86° F on average for the month of July. Based on data compiled by EPA (1992c), the air temperature within an enclosure may be as much as 20° F above the ambient outdoor temperature. In addition, wearing Level B PPE, including an impermeable suit with boots, gloves, hard hat, and full-face respirator, increases the temperature experienced by the worker by 10° to 20° F (Paull and Rosenthal 1987). Therefore, workers in the enclosure at the Tyson's Site could be exposed to temperatures in the range of 100° to 110° F for a significant portion of the year and to temperatures over 120° F during the hottest part of the summer, thereby creating the potential for serious health consequences even in Level B PPE.

The National Institute for Occupational Safety and Health (NIOSH) has recommended limits for worker protection from heat stress. The NIOSH Recommended Exposure Limit (REL) is 90° F for workers, wearing semi-permeable or impermeable suits, engaged in light work for 15 minutes per hour. The REL represents the level that heat-acclimatized workers should be capable of tolerating without adverse effects, and above which unprotected workers should not be exposed. The NIOSH-recommended ceiling limit (above which no worker should be exposed without heat protective measures) for heat-acclimatized workers engaged in light work is 104° F. During the summer months, it is very likely that a temperature of 104° F will be exceeded within the Level B PPE suit.

Because of the potentially serious nature of heat stress and heat stroke, NIOSH recommends certain precautions. For example, for workers wearing semi-impermeable or impermeable PPE, periodic monitoring of body temperature is suggested at temperatures in excess of 70° F, according to NIOSH; above 90° F, workers engaged in light work should be monitored every 15 minutes of work. Monitoring can only be conducted outside the work area; therefore, a worker would have to go through decontamination, remove respiratory equipment, and partially remove PPE. This type of monitoring schedule would greatly hinder the efficiency of

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the worker and cause significantly decreased productivity.

Another potential result of excess heat is the corresponding decrease in mental alertness and physical performance of workers. Increased body temperature and physical discomfort can distract workers from normal safety routines. According to an Army study on the risk associated with chemical disposal, a five-fold increase in forklift accident frequency was observed between workers in Level D and workers in Level B/C. An additional two-fold increase was anticipated between workers in Level B/C and workers in Level A.

2.   Accidents

The types of physical hazards that are experienced within an enclosure are not significantly different from those that would be experienced without the enclosure; however, the likelihood that an accident will occur is increased, and the consequences are likely to be more severe. Space limitations and equipment modifications, such as exhaust hoses on the diesel equipment and machinery (e.g. front-end loader), will reduce mobility and present additional hazards involving heavy equipment. The use of PPE will increase the potential for accidents and injury as a result of reduced mobility, communication, and vision. For example, the use of PPE equipment could result in fogged face masks that reduce visibility and muffled hearing and speaking due to enclosed hoods and noises emitted by the PPE equipment. It has been shown that workers commit more unsafe acts as PPE levels increase (Ramsey et al. 1983). The presence of the enclosure exacerbates the negative aspects of PPE.

The absence of information regarding accident frequency during hazardous waste remediation precludes a quantitative estimation of these types of risks to workers within the enclosure. The potential risks of chemical exposure to airborne contaminants within the enclosure as a result of an accident or equipment malfunction, however, can be evaluated quantitatively.

3.   Chemical Exposure

The soil handling and processing activities that are expected to be conducted within an enclosure at the Tyson's Site will include soil dumping from a dump truck used to transport soil from the active excavation area, separation of large boulders, boulder pickup and movement and loading into roll-off containers by a front end loader. Each soil handling activity is expected to release contaminant vapors to the atmosphere within the enclosure. As a rough estimate, vapor emissions within the

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enclosure are estimated to be approximately equivalent to emissions occurring outside the enclosure. Using EPA-suggested vapor emissions models for soil handling activities, order-of-magnitude estimates of high-end emission rates are presented in Table 29 as are exposure levels that are immediately dangerous to life or health (IDLH) as determined by NIOSH.

Average air concentrations of contaminants are estimated based on the emission rates in Table 29 and an estimated exhaust air flow rate of the enclosure's ventilation system, using the following equation:

$$C_A = \frac{ER}{Q} \tag{4}$$

where:

C_A	=	Average air concentration in the enclosure, g/m^3
ER	=	Volatile compound emission rate, g/sec
Q	=	Volumetric flow rate of the enclosure ventilation system, m^3/sec

Assuming an enclosure volume of approximately 2,700 m^3 (80 ft x 60 ft x 20 ft) and that the air within the enclosure will be exchanged once per hour, the volumetric flow rate of the ventilation system will be approximately 0.75 m^3/sec. For example, based on a 1 gram per second emission rate within the enclosure, the resulting airborne chemical concentration would be 1.3 g/m^3. This concentration is less than the IDLH value for all of the chemicals of potential concern listed in Table 29. It should be noted, however, that the emission rates used in the above equation were estimated based on overall average concentrations in soil at the site. Maximum concentrations of certain constituents (e.g., 1,2,3-trichloropropane, xylenes) could be more than an order of magnitude greater. It is possible, therefore, that the IDLH concentration will be exceeded within the enclosure during periods when soil containing high concentrations of contaminants is processed (e.g., processing of soils from DNAPL-containing areas). Accidents or equipment malfunctions occurring during these periods could lead to high levels of exposure comparable to the IDLH.

4.   Noise

Federal occupational noise standards require "protection against effects of noise exposure" when workers are exposed to noise levels of 90 dBA or more for

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TABLE 29 Order-of-Magnitude Estimates of Volatile Compound Emission Rates and NIOSH Immediately Dangerous to Life or Health (IDLH) Values			
Compound	Emission Rate g/s	Estimated Air Concentration g/m^3	IDLH ppm (g/m^3)
Benzene	0.01	0.01	3000 (9.9)
Ethylbenzene	1.0	1.33	2000 (8.8)
Tetrachloroethene	0.1	0.13	500 (3.4)
Toluene	1.0	1.33	2000 (7.6)
Trichloroethene	0.01	0.01	1000 (5.5)
1,2,3-Trichloropropane	1.0	1.33	1000 (6.3)
Xylenes	1.0	1.33	1000 (4.4)

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eight hours in one day (29 CFR, 1910.95). The noise levels within the enclosure may well be in excess of federal standards because of the proximity of workers to earth-moving equipment and soil processing units and may pose a significant risk of permanent hearing loss unless protection is worn. However, the introduction of hearing protection creates additional hazards to workers' safety by severely restricting workers' ability to communicate. Workers that are already hampered by the extreme temperatures, immobility, and poor vision associated with Level B PPE will also be denied their sense of hearing, thereby exacerbating an already hazardous working atmosphere.

C.   Odor Impacts

In 1983, EPA received citizen complaints regarding odors emanating from the Tyson's Site. As a result, EPA took remedial measures pursuant to CERCLA, which included: installing a leachate collection system to reduce contaminated discharges to the Schuylkill River, constructing an air stripping treatment system to remove volatile organic compounds from the leachate, partial site capping, and regrading, in an attempt to mitigate the immediate sources of odors and potential human health hazard. Since the implementation of the SVE system significant odor complaints have not been reported.

As has been shown at Superfund remediation projects at various locations in the United States, community exposure to odors can cause vomiting, headaches, dizziness, and respiratory problems due to large-scale excavation projects where the presence of odorous compounds has been documented. For example, at the Petro-Processors' site in Baton Rouge, Louisiana, odor problems encountered during waste excavation resulted in a complete reevaluation of remedial alternatives. Even with the use of foams, plastic, and dirt cover, odor problems at the site could not be controlled (NCP Services, Inc. 1988). Similarly, at the Boucher Landfill in Huntington Beach, California, work was delayed after officials received over 500 odor complaints from residents. At the Kellog Terrace site in Yorba Linda, California, over 600 complaints of illness and odors were received in the first two weeks of excavation from people in the vicinity of the site, prompting the local air quality management district to issue public nuisance citations. Residents there experienced vomiting, headaches, dizziness, and respiratory problems due to odors as a result of excavation.

Because odors have, in the past, been associated with the contaminants at the Tyson's Site, and because of the likelihood of significantly increased emissions during excavation, it is possible that complaints of odors emanating from the site may occur if extensive soil excavation is required.

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VIII. RISKS ASSOCIATED WITH RAIL TRANSPORT

A. Introduction

Contaminated soil excavated under the off-site incineration/disposal alternative will be transported using rail cars, which pose a finite level of risk of accidents, injuries, or fatalities. Although quantitative, the assessment of these types of risks is performed using a different methodology from that used to estimate risk associated with chemical exposure. Risks associated with rail transport are expressed as the number of accidents, injuries, and fatalities expected to occur during the transport process. These risks are based on the most recent carrier-specific data available (USDOT 1993), which are assumed to be a reflection of the current operating procedures and safety precautions of the rail carriers.

B. Rail Haul Process

As described earlier, the Tyson's Site is bordered on the north by a Conrail switching yard. This allows ready access to the Conrail system; therefore, Conrail will likely be the rail carrier. The most likely scenario for disposal will involve loading excavated soil into roll-offs within the soil processing enclosures, transporting the roll-offs to a loading platform, which will be constructed on an uncontaminated portion of the site, and loading the roll-offs onto empty rail cars supplied by Conrail each day. Loading the roll-off cars directly onto the rail cars at the site will avoid accidents that might occur if truck transport of the roll-off cars to an off-site location was necessary. It is estimated that approximately 200 tons of excavated soil could be removed from the site each day using this process, thereby requiring two rail cars. Loaded cars will be removed from the site daily by Conrail and transported to an off-site incineration/disposal facility selected by the RPs.

C. Possible Disposal Sites

Several possible combinations of incineration and disposal are possible for the soil excavated from the site. This analysis assumes that the soil will require incineration followed by disposal of ash in a landfill. Several incinerator site/landfill options are described in this section. Key considerations for evaluating these options include accessibility to the facility by railroad, distance from the Tyson's Site to the incinerator

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facility, and distance between the incinerator and landfill. Information regarding the disposal facilities and their requirements for accepting treated materials were obtained from discussions with facility personnel. A summary of four disposal alternatives is provided in Table 30.

1. **APTUS, Coffeyville, Kansas**

The APTUS incinerator is located in Coffeyville, Kansas, approximately 1,200 miles from the Tyson's Site. The plant has a railroad spur with the capacity to receive bulk shipments at a rate of approximately two rail cars per day (at about 100 tons per car). The material would be transported by rail to Coffeyville and unloaded with a clam-shell crane into a closed and cement-lined pit. The clam-shell crane would also be used to load the material into a shredder, followed by incineration. The incinerator ash would then be landfilled in either the USPCI Lone Mountain (approximately 300 miles away) or Grassy Mountain (approximately 900 miles away) landfills.

2. **ENSCO, El Dorado, Arkansas**

The ENSCO incinerator is located in El Dorado, Arkansas, approximately 1,200 miles from the Tyson's Site. The plant does not have a railroad spur into the site. The plant has a capacity to process materials at a rate of approximately two rail cars per day. Material from the Tyson's Site would be transported by rail to Little Rock, Arkansas, where the roll-offs would be loaded onto tractor trailer beds and driven to El Dorado. Here, the cars would be unloaded by hand under shelter, packaged into cubic yard boxes, and automatically fed into the incinerator. The incinerator ash/treated soil would be landfilled in either the USPCI Grassy Mountain landfill or the ChemWaste landfill in Mobile, Alabama.

3. **Rollins (RES Texas), Deer Park, Texas**

The Rollins incinerator is located in Deer Park, Texas, approximately 1,500 miles from the Tyson's Site. The plant cannot accept bulk material by rail, but can accept roll-off cars from tractor trailers. Therefore, material from the Tyson's Site would have to be transported by tractor trailer beds to Deer Park, unloaded with a clam-shell crane into a closed and cement-lined pit and/or into a shredder, and augured into the incinerator. The incinerator ash would then be landfilled at the RES Texas landfill on-site.

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TABLE 30
Comparison of Incinerator/Landfill Disposal Options for the Tyson's Site

Incinerator Site	Distance from Site	Railroad Access?	Capacity[a]	Landfill Site	Rail Distance to Landfill
APTUS Coffeyville, KS	1,200 mi.	Y	200 ton/day	USPCI Lone Mt.	300 mi.
				USPCI Grassy Mt.	900 mi.
ENSCO El Dorado, AR	1,200 mi.	N	200 ton/day	USPCI Grassy Mt.	NA
				ChemWaste Mobile, AL	NA
Rollins Deer Park, TX	1,500 mi.	N	600 ton/day	RES Texas	on-site
USPCI Clive, UT	2,200 mi.	Y	200-400 ton/day	USPCI Grassy Mt.	adjacent

a -   Based on 100 tons per car
NA - Not available

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4. USPCI, Clive, Utah

The USPCI incinerator is located in Clive, Utah, approximately 2,200 miles from the Tyson's Site. The plant has a railroad spur into the site with a capacity to take bulk materials at a rate of approximately 200-400 tons per day. Material from the Tyson's Site would be transported to Clive by rail and end-dumped into a storage pit. The materials would then be fed into the incinerator. The treated soil would be landfilled in the adjacent USPCI Grassy Mountain landfill.

D. Likelihood of Rail Accidents, Injuries, and Fatalities

The risks of accidents, injuries, and fatalities resulting from the rail transport of treated material from the Tyson's Site to an off-site disposal location are estimated in this section. The likelihood of such occurrences may be estimated by combining accident frequency data with assumptions about the route traveled, distance covered, and the expected number of trips required.

Because of the advantages of having direct access to the railroad, only the APTUS and USPCI sites are considered in this analysis. Using ENSCO or Rollins would require transport by truck for all or part of the process, thereby requiring double handling of the material. It is assumed that these additional costs/risks make ENSCO and Rollins less likely alternatives than APTUS or USPCI.

The total volume of unsaturated soil to be excavated from the Tyson's Site is 13,070 yd^3. Assuming a soil density of 1.51 tons/yd^3, the excavated mass is approximately 19,600 tons and the number of rail cars required, assuming a car capacity of 100 ton/car, is:

$$\frac{Total\ railcars}{required} = \frac{Total\ mass}{Car\ capacity} = \frac{19,600\ tons}{100\ ton/car} = 196\ railcars \qquad (5)$$

In order to take into account the fact that the rail cars with material from the Tyson's Site will only occupy part of an entire train (70 cars total), the number of "equivalent" trains, consisting entirely of rail cars with excavated material, is:

$$\frac{Total\ equivalent}{trains\ required} = \frac{Total\ railcars\ required}{Average\ number\ of\ cars/train} = \frac{196\ cars}{70\ cars/train} = 2.8\ trains \qquad (6)$$

For the USPCI site, the number of miles traveled by these 2.8 equivalent trains from Tyson's to Clive, Utah, is:

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$$Total\ mileage = (Number\ of\ trains) \ * \ (Miles/train)$$

$$= (2.8\ trains) \ * \ (2,200\ miles/train) = 6,160\ miles \tag{7}$$

Because the USPCI Grassy Mountain landfill is adjacent to this site, no further railroad transportation is needed for bringing the incinerator ash to the landfill.

For APTUS, the landfills are at different locations and additional transportation is needed to bring the reduced volume of material to the landfill. Assuming a 25 percent reduction in mass after incineration due to combustion/volatilization of VOCs and water, the mass of material to be transported from the incinerator to the landfill is 14,700 tons. The transport of the 14,700 tons of ash will require an additional 147 rail cars, or 2.1 additional equivalent trains for that portion of the overall process. Therefore, the total miles associated with APTUS/Lone Mountain is:

$$Total\ mileage = \left(2.8 \ \frac{trains}{to\ APTUS}\right) \ * \ (1,200\ miles/train)$$

$$+ \left(2.1 \ \frac{trains}{to\ Lone\ Mt.}\right) \ * \ (300\ miles/train) = 3,990\ miles \tag{8}$$

and with APTUS/Grassy Mountain is:

$$Total\ mileage = \left(2.8 \ \frac{trains}{to\ APTUS}\right) \ * \ (1,200\ miles/train)$$

$$+ \left(2.1 \ \frac{trains}{to\ Grassy\ Mt.}\right) \ * \ (900\ miles/train) = 5,250\ miles \tag{9}$$

The distance travelled by the total number of equivalent trains was combined with train accident and casualty data to estimate the risks associated with the transport of the excavated material by rail to the disposal site.

The most recent accident and casualty data specific to Conrail were given in the *Accident/Incident Bulletin No. 161, Calendar Year 1992* (USDOT 1993). In this report, the Federal Railroad Association (FRA) reports data for train-related incidents, defined as "any event involving the movement of railroad on-track equipment" that results in an accident or casualty, and non-train incidents, defined as casualties associated with a specific company, but not necessarily from the movement of cars. Non-train incidents were not included in this analysis because these types of casualties are not expected to be related to the transport of material.

In 1992, Conrail trains travelled 4.3×10^7 miles and were involved in 159 accidents,

resulting in 342 injuries and 118 fatalities (USDOT 1993). Based on these data, the number of accidents, injuries, and fatalities that are expected as a result of the transport of material by rail from the Tyson's Site to a disposal site can be calculated. For example, estimates of accidents and casualties associated with using USPCI are calculated as follows:

$$Number\ of\ Accidents\ =\ (6,160\ miles)\ *\ \frac{159\ accidents}{4.3\times10^7\ miles}\ =\ 0.023\ accidents \quad (10)$$

$$Number\ of\ Injuries\ =\ (6,160\ miles)\ *\ \frac{342\ injuries}{4.3\times10^7\ miles}\ =\ 0.049\ injuries \quad (11)$$

$$Number\ of\ Fatalities\ =\ (6,160\ miles)\ *\ \frac{118\ fatalities}{4.3\times10^7\ miles}\ =\ 0.017\ fatalities \quad (12)$$

The estimated number of accidents and casualties for disposal at APTUS and USPCI are summarized in Table 31. As indicated in Table 31, the likelihood of an accident ranges from 1.5 percent to 2.3 percent for the two facilities considered. The likelihood of an injury or fatality ranges from 3.2 percent to 4.9 percent and 1.1 percent to 1.7 percent, respectively.

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TABLE 31 Estimates of Accidents and Casualties Associated with Transport of Material from the Tyson's Site to the Disposal Site by Rail				
Incinerator Site	Landfill Site	Number of Accidents	Number of Injuries	Number of Fatalities
APTUS Coffeyville, KS	USPCI Lone Mt.	0.015	0.032	0.011
	USPCI Grassy Mt.	0.019	0.042	0.014
USPCI Clive, UT	USPCI Grassy Mt.	0.023	0.049	0.017

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IX.   UNCERTAINTIES AND LIMITATIONS

Risk assessment provides a systematic means for organizing, analyzing, and presenting information on the nature and magnitude of risks posed by chemical exposures. Nevertheless, uncertainties and limitations are present in all risk assessments because of the quality of available data and the need to make assumptions and develop inferences based on incomplete information about existing conditions and future circumstances. These uncertainties and limitations should be recognized and considered when evaluating quantitative risk estimates. Recognizing the limitations and uncertainties of risk assessments, government agencies have adopted risk assessment to provide a quantitative and consistent framework for systematically evaluating human health risks.

In general, the uncertainties and limitations in this risk assessment can be classified in the following areas:

- toxicological assessment
- characterization of environmental concentrations
- air dispersion modeling
- exposure assessment

A.   Uncertainties in the Toxicological Assessment

In the majority of risk assessments, as in this risk assessment, available scientific information is insufficient to provide a thorough understanding of all the toxic properties of chemicals to which humans are potentially exposed. It is generally necessary, therefore, to infer these properties by extrapolating them from data obtained under other conditions of exposure, generally in laboratory animals.

Experimental animal data have been relied upon for many years by regulatory agencies and other expert groups for assessing the hazards and safety of human exposure to chemicals. This reliance has been supported in general by empirical observations. There may be differences in chemical absorption, metabolism, excretion, and toxic response, however, between humans and the species for which experimental toxicity data are generally available. Uncertainties in using animal data to predict potential effects in humans are

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introduced when routes of exposure in animal studies differ from human exposure routes, when the exposures in animal studies are short-term or subchronic, and when effects seen at relatively high exposure levels in animal studies are used to predict effects at the much lower exposure levels found in the environment. The methods for dealing with these uncertainties in the toxicological assessments for noncarcinogens and carcinogens are discussed below.

1.   **Uncertainties in the Characterization of the Toxicity of Noncarcinogens**
       To adjust for uncertainties such as those discussed above, EPA and other regulatory agencies typically base the RfD (or other expression of the acceptable daily intake) for noncarcinogenic effects on the most sensitive animal species, i.e., the species that experiences adverse effects at the lowest dose. This dose is then adjusted by the use of safety factors or uncertainty factors to compensate for the lack of knowledge regarding interspecies extrapolation and to guard against the possibility that humans may be more sensitive than the most sensitive experimental animal species tested. The resulting toxicity factor incorporates a substantial margin of safety, although the actual size of this safety margin cannot be quantified with any certainty.
       Inhalation noncancer toxicity values for three chemicals of potential concern evaluated in this assessment, PCE, TCP, and xylene, have not been developed or verified by EPA. Therefore, to account for inhalation exposures to these chemicals that have noncancer effects due to oral exposure, inhalation toxicity values (inhalation RfDs) were estimated for PCE, TCP, and xylenes based on the published oral RfD (i.e., a route-to-route extrapolation). Certain limitations are introduced with such route-to-route extrapolation with respect to: (a) the applicability of extrapolating when the exposure route is the critical target organ; (b) first pass effects; and (c) the effect of the exposure route on dosimetry. The critical effects for PCE and xylenes (i.e., the health effects on which the RfDs are based) are liver toxicity and whole body weight loss, respectively. For TCP, clinical chemistry changes were observed in the critical toxicological study. It is unknown whether these effects may or may not be specific to the oral route of exposure. (The critical study route of exposure for PCE, TCP, and xylenes was gavage.) The effect of using the oral RfD to estimate the inhalation RfD in these cases is uncertain.

2.   **Uncertainties in the Characterization of the Toxicity of Carcinogens**
       For many substances that are carcinogenic in animals there is uncertainty as to

whether they are also carcinogenic in humans. While many substances are carcinogenic in one or more animal species, only a few substances are known to be human carcinogens. The fact that some chemicals are carcinogenic in some animals but not in others raises the possibility that not all animal carcinogens are human carcinogens as well as the possibility that not all human carcinogens are animal carcinogens. The finding that relatively few substances are known human carcinogens may be due in part to the difficulty in conducting adequately designed epidemiologic investigations in exposed human populations. Regulatory agencies generally assume that humans are as sensitive to carcinogens as the most sensitive animal species. In addition, there are several mathematical models available to derive low-dose unit risks from high exposure levels used in experiments. The model used by EPA is the linearized multistage model, which generally provides the most conservative estimate of risk at low doses (i.e., highest risk/dose). The lack of knowledge regarding the validity and accuracy of this model, however, contributes to uncertainties in cancer risk estimates.

For suspected carcinogens, the normal procedure used by EPA is to use the 95 percent upper confidence limit estimated by the linearized multistage model. Use of the 95 percent upper confidence limit value, rather than the unit risk that represents the maximum likelihood estimate, provides an estimate of the upper boundary on risk according to EPA (1989).

3. Uncertainties in the TCP Cancer Potency Estimate

The primary chemical driving this assessment is TCP. As with all chemicals on which risk assessments are conducted, there are uncertainties in the toxicity values used. In the case of TCP, the primary effect of concern is its potential carcinogenicity. Uncertainties in the EPA estimate of cancer potency arise from four major areas discussed below. All tend to exaggerate the potency estimate, suggesting that the true potency of TCP is lower than that calculated by EPA.

a) High to Low-dose Extrapolation

Because of the necessity to extrapolate from the high dose levels at which tumors were observed in the NTP (1993) bioassay (3 to 30 mg/kg/day) to the low doses to which humans may be exposed (generally less than 10^{-5} mg/kg/day), it is necessary to use some sort of low-dose extrapolation model. As noted above, the model generally used by EPA for this purpose is

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the linearized multistage model. This model has been used by regulatory agencies because of its conservatism (it yields an <u>upper limit</u> on potency), its basis in the multistage theories of cancer development, and its versatility in providing good fits to many cancer data sets. It cannot, however, take into consideration certain data on the mechanism of cancer development that appears to be of growing importance, particularly data on the influence of chemicals on cell proliferation. Other plausible models may produce quite different estimates of cancer potency.

b)   Interspecies Extrapolation

There are no data implicating TCP as a human carcinogen from which an estimate of potency in humans can be derived. It is, therefore, necessary to extrapolate from experimental animal data to humans, another source of uncertainty. In performing interspecies extrapolation, it is normal practice to make adjustments for interspecies differences in body size, lifespan, and other factors. This is an area where substantial debate exists as to the most appropriate procedure to use. Historically, EPA has used body surface area scaling (or body weight to the 2/3 power) for interspecies scaling, while FDA, for example has used body weight scaling. This can result in a difference in potency estimate for the same chemical of about seven-fold with rat data to 14-fold with mouse data. More than two years ago, EPA proposed changing their default procedure for interspecies scaling, moving to an intermediate method based on body weight to the 3/4 power (57 FR 24152, June 5, 1992). This method was selected as a compromise that all regulatory agencies could agree on. To date, however, the compromise has not been adopted. Its use would result in a potency factor about 1.5- to 2-fold lower than the current EPA value.

While use of such a measure of systemic dose may be appropriate for carcinogens that act systemically at sites distant from the initial point of contact, it may not be appropriate for the forestomach tumors induced by TCP. In this case, the action on the forestomach is likely to reflect the local concentration of the chemical, or its metabolites, not the systemic dose. A more appropriate approach to interspecies extrapolation in this situation might be based on a time-integrated measure of local concentration of TCP, its active metabolite(s), DNA adducts, or some similar measure of target-site dose.

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c)   **Inter-route Extrapolation**

It is well known from experimental studies that the route and method of administration of a chemical can influence the carcinogenic response that is produced, both qualitatively and quantitatively, and hence the potency estimate derived from the data. Some chemicals, such as hexavalent chromium and formaldehyde, appear to be carcinogenic by inhalation but not by ingestion. Others, such as 1,2-dichloroethane, show the opposite pattern. In other cases, the target site differs when a different exposure route is used, and most chemicals show differences in carcinogenic potency by different routes of exposure (IRIS 1994). There may be several explanations for these differences, but the primary reason is likely to be related to pharmacokinetics and metabolism. The portal of entry of the chemical may be exposed to relatively high concentrations, especially when administration is by gavage. If the chemical is a direct-acting carcinogen, or if the local tissue (lung, stomach epithelium) can metabolize it to an active form, and if that tissue is susceptible to the carcinogenic effect of the chemical or its metabolites, tumors may arise preferentially at the site of administration (e.g., nose or lung by inhalation; forestomach by ingestion). Because chemicals administered orally (either by gavage or in feed or drinking water) pass directly from the gut via the portal system to the liver, they may be subject to first-pass metabolism. This in turn may either increase or decrease the carcinogenic response, depending upon whether the liver detoxifies or activates the chemical, and what tissue is susceptible to the carcinogenic effect of the chemical. Even differences in the method (gavage and administration via feed or drinking water) and vehicle (corn oil or water) of oral administration can result in differences in the concentration of the chemical at the portal of entry, and in the liver, with consequent differences in response.

In the case of TCP, the only available carcinogenicity data come from a corn oil gavage study. There are several examples of chemicals, including halogenated hydrocarbons like TCP, which produced an exaggerated tumor response when administered by gavage compared with a more realistic route, such as dietary incorporation, or drinking water incorporation. These include chloroform (ATSDR 1993), 1,2-dibromo-3-chloropropane (DBCP) (USEPA 1983), and 1,2-dichloroethane (Klaunig et al. 1986). In the case of chloroform, EPA has acknowledged differences in carcinogenic potency by

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gavage and drinking water exposure. The agency derived a cancer potency factor of 8.1 x 10^{-2} (mg/kg/day)$^{-1}$ from data on gavage administration of chloroform, while the potency derived from data on exposure via drinking water was 6.1 x 10^{-3} (mg/kg/day)$^{-1}$, a value 13-fold lower than the gavage potency (ATSDR 1993).

In the case of DBCP, EPA derived a relative potency factor for the gavage and dietary routes and used this relative potency factor (0.5897) to adjust the potency estimate derived from a gavage study of a related chemical, ethylene dibromide (EDB), to derive an equivalent dietary potency (USEPA 1983). Similarly, with 1,2-dichloroethane, a dose level more than three-times higher than the gavage dose that produced liver tumors in mice produced no increase in liver tumors when administered in drinking water (Klaunig et al. 1986).

Another chemical, though not a chlorinated alkane, may also provide some insight on this issue. Dinitrosopiperazine produced forestomach squamous cell carcinoma in mice when administered by gavage at 2.56 mg/kg/day. When the chemical was incorporated in drinking water, delivering doses of 8.67 mg/kg/day (males) or 10.4 mg/kg/day (females), no increase in forestomach tumors in treated mice was seen. Although there was an increase in incidence of lung tumors by the latter route of administration, the resultant estimate of cancer potency (as expressed by the TD_{50}) was about four-fold lower with drinking water exposure than with gavage exposure (Gold et al. 1984).

These findings suggest that the potency estimate derived from the TCP gavage data may exaggerate the potency of TCP received by a more realistic method of exposure. In addition, the major tumor types found in TCP-dosed animals were oral cavity and forestomach squamous cell tumors. This suggests a contact-site phenomenon that might be less strong with a method of exposure producing a more uniform exposure rather than the bolus dose produced by gavage.

d)   **Species/Tissue Specificity of Tumorigenic Effect**

In both rats and mice, the tissue most sensitive to the development of tumors following TCP gavage was the forestomach. This organ does not occur in humans, however. If the sensitivity of the forestomach in rodents

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reflects some tissue-specific feature, therefore, one would not expect comparable sensitivity in humans. This would be true whether the sensitivity of the forestomach is due to some specific physiological or biochemical property (e.g., an unusual ability to activate TCP to a carcinogenic form), or whether it is due simply to an anatomical feature (e.g., acting as a reservoir of gavage fluid containing a high concentration of TCP with a long transit time, resulting in unusually high local dose levels of TCP, and its reactive metabolites, as measured by [concentration] x [time]).

4. Uncertainties in the Assessment of Chemical Mixtures

The Hazard Index (HI) approach for the noncarcinogenic effects of chemicals assumes that multiple sub-threshold exposure could result in an adverse effect and that a reasonable criterion for evaluating the potential for adverse effects is the sum of the hazard quotients for individual chemicals. This methodology, however, is most appropriately applied to substances that induce the same effect on the same organ. Therefore, to the extent that toxic effects of the chemicals of potential concern are not additive, the HI approach is likely to result in an overestimate of potential risk. As indicated in Table 32, for the chemicals of potential concern with noncancer effects, the liver is the target organ for three of the four compounds, although the effect is not the same in every case (toxicity versus weight change). Therefore, the HI approach may overestimate the potential for noncancer effects.

Cancer risks for multiple chemical exposures are assumed to be additive. As noted by EPA (1989), there are several limitations to this assumption of additivity. One of these limitations arises from the fact that risks are based on unit cancer risks that are derived as upper 95th percentiles of the probability distributions of cancer potency. Because upper 95th percentiles of probability distributions are not strictly additive, the total cancer risk estimate can become artificially more conservative as risks from a number of carcinogens are added. Secondly, the approach routinely applied in cancer risk assessment treats all carcinogens equally, regardless of the weight-of-evidence class to which a carcinogen is assigned. Each class is given equal weight; known carcinogens (class A) are considered equal to probable and possible carcinogens (classes B and C) in the summation of risks. As shown in Table 32, benzene is classified as a known carcinogen (class A), and PCE, TCE, and TCP are

TABLE 32					
Health Effects and Target Organs for Noncarcinogenic and Carcinogenic Chemicals of Potential Concern					
Chemical	**Noncancer Effect**		**Cancer Endpoint**		
	Oral	**Inhalation**	**Oral**	**Inhalation**	**Weight-of-Evidence**
Benzene	NA	NA	Leukemia		A
Ethylbenzene	Liver and kidney toxicity	Developmental Toxicity	NA		NA
Tetrachloroethene	Liver toxicity	NA	Not provided		B2
Toluene	Liver and kidney weight change	Degeneration of nasal epithelium and neurological effects	NA		NA
Trichloroethene	NA	NA	Liver	Lung	B2
1,2,3-Trichloropropane	Clinical chemistry changes	NA	Multiple sites	NA	B2
Xylenes	Decreased body weight, hyperactivity, increased mortality	NA	NA	NA	NA

probable carcinogens (class B2). Finally, the mechanism of action of any two carcinogens may not be the same and, in fact, might be independent. The cumulative risk estimates provided in this assessment are based on the assumption that mechanisms of action are similar. As shown in Table 32, however, this assumption may not be entirely valid and may overestimate risks.

It is also assumed that mixtures of chemicals do not act antagonistically or synergistically. The combined risk of antagonistic chemicals is expected to be less than the sum of the individual risks; whereas, the total risk from synergistic chemicals would be greater than the sum of the individual risks. Data to assess quantitatively these types of interactions, however, are not available. To this end, cancer risks may be over- or underestimated by the approach applied here.

B.   Uncertainties in the Characterization of Environmental Concentrations

Exposure to chemicals of potential concern during both implementation and after completion of the remedial alternative may occur due to direct exposure to chemicals in soil or to airborne chemicals that have volatilized from soil. To estimate the magnitude of this exposure, it is necessary to characterize the concentrations of contaminants in soil, model the volatilization of chemicals to the atmosphere, and estimate airborne concentrations. The sections below discuss the uncertainties associated with characterizing soil concentrations and modeling the volatilization of chemicals on-site. Estimation of airborne concentrations is performed using air dispersion modeling; the uncertainties associated with air dispersion modeling are discussed in section C of this chapter.

1.   Characterization of Soil Concentrations

In this risk assessment, average and reasonable maximum soil concentrations are estimated based on the arithmetic mean and the 95 percent UCL of the arithmetic mean of soil data collected in 1988 (ERM 1989) and 1993 (ERM 1993), as recommended by EPA (1989). Additional soil concentration data have been collected historically, in the early 1980s, during the remedial investigation and followup studies performed by EPA. These sources of data are generally consistent with the ERM data but were not subjected to the rigorous quality assurance/quality control (QA/QC) procedures used for the ERM data. Consequently, only the ERM data was used in this assessment.

The 1988 ERM data was collected before the SVE system was fully operational. Although significant extraction of volatile compounds has occurred

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(almost 200,000 pounds of VOCs have been removed), field observations have indicated that DNAPL contours in the subsurface have not appreciably changed over the years. Therefore, use of the 1988 ERM data is considered conservative in that it may overestimate actual soil concentrations at depth.

In addition, there is uncertainty in the representativeness of the soil sampling data due to the spatial distribution of sampling locations, especially for subsurface soils. The 1988 subsurface soil sampling was conducted in soil borings collected from the soil vapor extraction wells, which are generally located in areas of elevated VOC concentrations. Significantly fewer samples were collected from the less contaminated portions of the site. Therefore, average and reasonable maximum soil concentrations in the unsaturated zone may be overestimated.

2. Estimation of Emission Rates

As discussed in detail in Appendix B, emissions of VOCs were estimated for several emission sources both during and after implementation of the remedial alternative (e.g., passive diffusion from DNAPL, increased volatilization due to excavation/soil handling).

a. Emissions Models

Emissions modeling was performed using models developed by EPA (for both excavation-associated emissions, and short- and long-term diffusion emissions). These models, however, are generally considered as screening models that provide a rough, upper-bound estimate of emissions. For example, the model used to estimate emissions due to excavation/soil handling should be regarded as providing order-of-magnitude estimates. An evaluation of the model's performance was conducted by the model developer by comparing model predictions with field data (USEPA 1992d). The model results agree with the field measurement within a factor of five for seven of the nine measurement. All estimates were within a factor of ten of the measured values.

The models used for long- and short-term passive diffusion emissions are also based on EPA-developed methods (USEPA 1986c;1988). The long-term passive diffusion model provides a steady-state emission rate and assumes that there is sufficient mass of contaminant in soil (e.g., DNAPL), so that depletion of the source is not an issue. Consequently, emissions were

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estimated in the risk assessment for areas of the site that contained DNAPL. In addition, the potential effects of biodegradation, adsorption, and retardation are not considered in this model. It is expected that these assumptions would tend to provide an overestimate of emissions. The short-term passive diffusion model is more refined and provides a unsteady-state estimate of emissions. The uncertainty associated with this model is unknown.

Significant uncertainty is associated with the emission rate estimates for the soil processing enclosure (under the on-site LTTD and off-site incineration/disposal alternatives). In neither alternative, however, do these emissions affect overall risk significantly (because of the removal efficiency of the air handling system for the enclosure).

b.   Model Input Assumptions

Just as important as the validity of the models is the representativeness of the site-specific input data used in the models. In order to model emissions of VOCs, numerous assumptions regarding the activities associated with the remedial alternatives (methodological assumptions), site-specific soil parameters, and chemical-specific parameters were used. These assumptions affect the estimated emission rates, and, consequently, air concentrations.

Methodological assumptions include, for example, parameters such as the excavation/grading area, volume of soil excavated, excavation/soil handling rate, and duration of implementation. These assumptions correspond directly to the implementation plan for the remedial alternatives developed for the FFS or are based on a simplified design, in which case parameter values were assigned so as to be conservative. In general, these plans are designed to be the most effective and efficient means of completing the remedy, based on the limitations of the site. Therefore, it is not expected that these parameters should change significantly. It is possible, however, if significant changes in the implementation plan occur that estimated emission rates based on these assumptions may under- or over-estimate actual emission rates.

To evaluate potential changes in remedial alternative design parameters, ENVIRON conducted a sensitivity analysis that compares human risks associated with two excavation scenarios: 1) excavation of the entire contaminated unsaturated zone; and 2) excavation of soil with total VOC concentrations in excess of 1,000 ppm. Several key parameters were changed

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in the sensitivity analysis to reflect the differences between the excavation scenarios, including the volume and location of excavation, and the average concentration of chemicals of potential concern in the excavated soil. Changes in the volume and location of excavation resulted in changes to the duration of excavation, air dispersion factors, and the fraction of excavation performed in each of the three former lagoon areas. A summary of these changes is provided in Table 33.

Implementation risks to an off-site resident associated with excavation of soils with total VOC concentrations in excess of 1,000 ppm were developed for excavation associated with the on-site LTTD and off-site incineration/disposal alternatives. A summary of the estimated lifetime TCP cancer risks (implementation, post-implementation, and total risks) for the two excavation scenarios (unsaturated zone and 1,000 ppm VOC contour) is provided in Table 34. As shown in Table 34, an increase in the design excavation volume does not necessarily result in significantly altered risks; however, it is anticipated that further decreases in excavation volume leave high residual concentrations on-site that may pose a risk to individuals entering the site.

The post-implementation risks in Table 34 are primarily attributed to VOC emissions from the DNAPL-impacted soils within the saturated zone and DNAPL in the saturated bedrock. A preliminary evaluation was conducted to assess whether risks could be lowered by excavating DNAPL-impacted soils in the saturated zone. This evaluation indicated that some decrease in post-implementation risks would result from excavating soils in the saturated zone, but that any risk benefit would be offset by a disproportionately larger increase in implementation risks. Implementation risks were estimated to increase to 6.5×10^{-5}. Consequently, no further engineering assessment was undertaken.

Additional assumptions include: model input parameter values, which are site- or chemical-specific. Values for site specific parameters, such as the total and air-filled porosity, bulk density, and fraction of organic carbon, for example, were assigned based on data collected during soil sampling episodes or on typical values for the type of soil present at the site. Historical sampling has indicated, however, that the soils on-site are heterogeneous; therefore, site-specific soil parameter values such as these may also vary widely across the site. Without extensive data collection, the actual range of values cannot be determined and the uncertainty associated with these parameters cannot be quantified.

Chemical-specific parameter values were obtained from the published literature and are considered reliable. All chemical-specific values used in the models are based on a temperature of 25° C (77° F). If implementation is conducted during a cooler part of the year and for soil located at depth, emissions may be overestimated. Emissions may be underestimated if implementation is conducted during the summer months.

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TABLE 33		
Comparison of Excavation Parameters Used in Sensitivity Analysis		
Parameter	Unsaturated Zone	Total VOC Concentration Greater than 1,000 mg/kg
Volume of Soil Excavated (yd³)		
Lower West	3,285	330
Upper West	5,475	3,980
Upper East	11,550	8,760
Total	20,310	13,070
Fraction of Excavation		
Lower West	0.15	0.025
Upper West	0.25	0.305
Upper East	0.60	0.67
Dispersion Factor (μg/m³ per g/sec)		
Lower West	8,731	7,769
Upper West	4,322	4,371
Upper East	1,836	1,759
Duration of Excavation (days)	154	99

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TABLE 34 Comparison of Estimated Lifetime TCP Cancer Risks to Off-Site Resident Under Two Excavation Scenarios (Sensitivity Analysis)		
Implementation Risks		
Excavation Scenario	**Average TCP Cancer Risk**	**Reasonable Maximum TCP Cancer Risk**
Unsaturated Zone	2.3×10^{-5}	4.8×10^{-5}
Total VOCs $>1,000$ ppm	1.8×10^{-5}	3.7×10^{-5}
Post-Implementation Risks		
Excavation Scenario	**Average TCP Cancer Risk**	**Reasonable Maximum TCP Cancer Risk**
Unsaturated Zone	7.3×10^{-6}	2.4×10^{-5}
Total VOCs $>1,000$ ppm	7.3×10^{-6}	2.4×10^{-5}
Total Risks		
Excavation Scenario	**Average TCP Cancer Risk**	**Reasonable Maximum TCP Cancer Risk**
Unsaturated Zone	3.0×10^{-5}	7.2×10^{-5}
Total VOCs $>1,000$ ppm	2.5×10^{-5}	6.1×10^{-5}

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Other assumptions that may affect the estimation of emission rates
include:

- It is assumed that emissions from excavation and soil handling activities
  will not occur at night due to covers or other vapor suppression
  measures. Although emissions during nonworking hours will likely be
  significantly less than during implementation, risks may be
  underestimated due to this assumption.

- No emissions from the truck transport of material across the site is
  considered. Covers will be used during the transport of materials
  across the site and it is likely that the duration of transport will be
  short; however, potential emissions from this source may increase risks
  associated with the alternatives that include excavation.

C.   Uncertainties in Air Dispersion Modeling

The long-term dispersion of emissions from the site was simulated using the ISCLT2
model. The algorithms in this model are regularly subjected to a peer review process to
incorporate the most recent developments. The ISCLT2 model is a recommended air
dispersion model for use at receptor elevations at or below emission height. This model is
generally recognized as being suitable for this type of application. Although mathematical
dispersion modeling is a generally accepted method of predicting exposures to airborne
pollutants, the validity of the results may be affected by inaccuracies in the input data or the
mathematical representation implicit in the model. Potential sources of such inaccuracies
include (1) an imprecise or incomplete description of the relevant meteorological phenomena
at the site (e.g., limitations due to the use of meteorological data from a weather station
several miles away from the site); and (2) an imperfect representation of the dispersion
process. Uncertainties in the ISCLT2 model predictions are generally less than 50 percent.

1.   Uncertainties Associated with Meteorological Data

The ISCLT2 model requires as an input average wind speed and frequency
data. This information is generally available from the National Climatic Data Center
in the form of a stability array (commonly referred to as a STAR summary) for
various National Weather Service monitoring stations located throughout the United
States. The data used in this assessment was collected at the Philadelphia

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International Airport. Significant uncertainty, however, is associated with the use of these data, primarily because of the unique topographic features at the site. The site is a former quarry and, consequently, is partially surrounded by a rock high-wall. The effect of this high-wall on the wind flow patterns in the vicinity of the site is unknown and is expected to be complex. Therefore, use of the Philadelphia International Airport wind data creates a significant source of uncertainty that cannot readily be quantified.

2.   Imperfect Representation of Air Dispersion

The ISCLT2 model is recommended by EPA for use at receptor elevations at or below the height of the emissions source (i.e., flat terrain). The topography in the vicinity of the site, however, is marked by a significant elevation change (high-wall) to the south of the site. In fact, Belmont Terrace, a residential subdivision located south of the site is at elevations of 50 to 100 feet above the site. The nearest residences to the site, however, are to the west at approximately the same elevation as the site and channeling of winds is expected in an east-west direction. As noted earlier, the ISCLT2 model is generally accurate within 50 percent. The complex nature of the surrounding topography near the site introduces significantly greater uncertainty to model predictions.

D.   Uncertainties and Variabilities in the Exposure Assessment

In any risk assessment, a large number of assumptions must be made to assess the magnitude of human exposure. In conducting an exposure assessment, it is necessary to develop assumptions about general characteristics and potential behavior patterns for exposed populations. In this risk assessment, both average and reasonable maximum exposure doses were estimated in order to provide a reasonable range of possible exposure and, subsequently, risks. The average exposure dose is developed to represent the median of the distribution of exposure doses for the entire exposed population. Whereas, the reasonable maximum dose represents an estimate of exposure for the upper end of the distribution, but not above the maximum expected value. This methodology is generally consistent with EPA guidance and is not expected to significantly underestimate actual risks within the exposed population. Data are available to estimate the variability of several exposure factors, such as inhalation rate, soil ingestion rate, and body weight, for example. EPA-suggested values representing the typical and upper bound values have been used in this assessment; therefore, the uncertainty associated with the use of such factors is likely small. Limited data are

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available, however, to characterize the variability associated with such factors as exposure time and frequency (e.g., the number of times and duration a child will trespass on-site), surface area of skin exposed, and the exposure duration (e.g., length of time residents live near the site). Therefore, there is significant uncertainty associated with the use of these values in the exposure assessment. It is expected, however, that by incorporating values for several factors that are believed to be toward the upper bound of possible values, a reasonable maximum estimate will result. Estimates of reasonable maximum exposure and risk, therefore, are expected to be conservative. Specific examples of uncertainty with regard to exposure dose estimation include:

- The actual time that an individual will spend on the site performing maintenance activities is uncertain. Once the remedy has been implemented, daily visits throughout the entire year are unlikely to be necessary. It is possible, however, that an individual may be located on-site continuously during the workday (i.e., 8 hours per day); therefore, the risk estimates for the maintenance worker exposure population may have some associated uncertainty.

- The soil ingestion and dermal contact routes of exposure have been evaluated in this assessment for the maintenance worker and trespassing child exposure populations for four alternatives: soil cover, wet soil cover, on-site LTTD, and off-site incineration. Each of these alternatives includes a two-foot soil layer that is designed to cover the contaminated areas of the site and protect against direct contact exposure. It is highly unlikely that routine soil ingestion or dermal contact exposure will occur for either of the exposure populations noted above. Risks due to this type of exposure estimated in this assessment, therefore, are likely to overestimate actual risks.

- Post-implementation off-site resident exposure is assumed to occur continuously (24 hours per day), 350 days per year for up to 30 years (under the reasonable maximum exposure. Although possible, this degree of exposure is likely to overestimate actual risks to individuals located in the vicinity of the site.

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E.   Other Sources of Uncertainty Associated with the Risk Assessment

In developing the scope of the risk assessment, some assumptions were made in order to focus the assessment on the most important exposure pathways, populations, and chemicals of concern. In doing so, total risks associated with the site and with remedial activities at the site may be underestimated. Specific sources of additional uncertainty include:

1.   Uncertainties in the Identification of Exposure Populations and Pathways

a.   Exposure Populations

In this assessment, risks are estimated during and after implementation for residents located adjacent to the site, and after implementation for an on-site maintenance worker and a trespassing child. Risks to workers engaged in excavation and soil processing activities at the site are evaluated qualitatively. While these are likely to be the populations with the highest risks, there are other populations that may be exposed to contamination on or from the site during and after implementation (e.g., railroad workers at the adjacent Conrail switching yard and trespassers on-site during implementation). This risk assessment was developed to provide an indication of comparative risks among the remedial alternatives for the site and is not necessarily designed to quantify the risks to all potentially exposed populations. Furthermore, considering the likelihood and extent of exposure to these populations, risks are not anticipated to be significant.

b.   Exposure Pathways

Assessment of inhalation exposure is limited to volatile chemicals released from site soils. Exposure through inhalation and ingestion of chemicals adsorbed to airborne dust (i.e., particulate matter) is not evaluated quantitatively. Because dust-associated chemicals may deposit off-site, individuals could be exposed through ingestion and dermal contact at off-site locations. The likelihood of exposure due to dust (through either inhalation or contact with deposited particulate matter) was not judged to be significant because of the volatile nature of the chemicals of potential concern, the use of dust suppression during implementation, and the distance from the site to the nearest residence. It is possible, however, that a slight incremental risk to off-site receptors (e.g., residents) may result from activities at the site, but it is

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not likely to be greater than those estimated.

2.   **Selection of Chemicals of Potential Concern**

Seven chemicals of potential concern were selected for analysis in this assessment based on the frequency of detection and potential toxicity. Risks from all chemicals detected at the site in any study or sampling event are not evaluated. It is anticipated that a significant fraction of the entire risk for each remedial alternatives will be associated with these chemicals. In fact, as indicated in the risk characterization (Chapter VI), TCP is by far the most significant source of risk at the site, due to the generally high concentrations detected on-site and a cancer slope factor that is significantly greater than that of other carcinogens. However, because exposure to all chemicals detected at the site is not included, total risks may be marginally higher than reported.

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APPENDIX A

Estimation of Soil Concentrations

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APPENDIX A: ESTIMATION OF SOIL CONCENTRATIONS

Exposure to chemicals of potential concern both during and following implementation of each remedial alternative may potentially occur from varying sources depending on the alternative and the activities involved (e.g., soil handling and excavation, grading, on-site treatment). In order to estimate this exposure, it is necessary to estimate concentrations of contaminants in environmental media, such as soil and air. The methodology that was used to estimate soil concentrations applicable to the following activities or potential sources of exposure is described in this chapter.

- Soil excavation/handling;
- Passive diffusion;
- Direct contact; and
- LTTD treatment residual.

Table A-1 indicates which of these activities/sources apply to each of the five alternatives.

A. Soil Concentrations Applicable to Soil Excavation/Handling

Excavation and soil handling associated with the remedial alternatives may involve partial removal of soil in the unsaturated zone or activities such as grading that are restricted to disturbances of the top layer of soil. Soil concentrations for different soil horizons, therefore, were estimated.

1. Excavation of Soils in the Unsaturated Zone

Two estimates of soil concentrations, average and reasonable maximum, were developed for the remedial alternatives that involve excavation of soils with total VOC concentrations in excess of 1,000 mg/kg. Because of the variability of concentrations across the site, area-specific soil concentrations were estimated for each of three sub-areas of the site: the lower west, upper west, and upper east lagoon areas. Concentrations were not estimated for the lower east area of the site because contaminant concentrations are significantly lower in this area and no concentrations

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TABLE A-1 Types of Methodologies Used to Estimate Soil Concentrations Associated with the Remedial Alternatives					
Activity/Methodology	**Remedial Alternative**				
	Soil Cover	**Capping**	**Wet Soil Cover**	**On-site LTTD**	**Off-site Incineration/ Disposal**

Soil Excavation/Handling of:
  1,000 mg/kg soils[a]
  Surficial soils[b]
	X	X	X	X	X

Passive Diffusion[c]	X	X	X	X	X
Direct Contact[d]	X		X		X
LTTD-Treatment Residual				X	

Notes:
a -   Soil concentrations estimated for soils with total VOC concentrations exceeding 1,000 mg/kg.
b -   Based on samples collected in the uppermost two feet of soil column
c -   DNAPL-containing soils
d -   Based on samples collected in the top three inches of soil column

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in excess of 1,000 mg/kg total VOCs have been detected.

To estimate average soil concentrations, soil sampling data compiled by ERM in 1988 (subsurface) and in 1993 (surficial soils to two feet) were categorized based on sampling depth and site sub-area (ERM 1989;1993). Additional data have been collected historically, in the early 1980s, which are generally consistent with the ERM data but were not subjected to the rigorous quality assurance/quality control (QA/QC) procedures used for the ERM data. Consequently, only the ERM data will be used in this assessment. Because the 1988 ERM data was collected before the SVE system was fully operational, a supplemental sampling program was instituted in 1993 to characterize contaminants in the top two feet of soil, where the effect of the SVE operation would be most pronounced. Although significant extraction of volatile compounds would also have occurred at depths of five feet or greater, field observations by Terra Vac have indicated that DNAPL contours in these zones have not appreciably changed over the years. Nonetheless, use of the 1988 ERM data is considered conservative in that it may overestimate actual soil concentrations at depth.

Three groups of soil samples were developed for each sub-area of the site. The first group is comprised of soil samples collected at a depth of 18 inches to 2 feet during the 1993 surface sampling episode. The second group is mostly comprised of soil samples collected at five feet. The third group of soil samples is comprised of samples collected between 8 and 12 feet, with the majority collected at 10 feet. Thus, samples in the three groups represent concentrations in the soil intervals 0 to 3.5 feet, 3.5 to 7.5 feet, and 7.5 to 10 feet. In this manner, the vertical distribution of contaminants at the site was incorporated into the analysis.

Based on total VOC contours developed by ERM, soil samples collected within the 1,000 mg/kg total VOC contour were selected for use in this analysis. Samples in this area were used to estimate concentrations in these highly contaminated areas. Average and reasonable maximum soil concentrations of the chemicals of potential concern were estimated for each soil interval, within the 1,000 mg/kg contour for each sub-area of the site. For the upper east lagoon area, arithmetic average and reasonable maximum concentrations in the unsaturated zone were developed for each soil interval to 10 feet. Reasonable maximum soil concentrations of the chemicals of potential concern were estimated based on the 95 percent upper confidence limit (UCL) of the mean using samples collected within each soil interval. Weighted averages for the upper east lagoon area were calculated based on the portion of the soil column represented by each soil interval, and the arithmetic averages and

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reasonable maximum soil concentrations for each soil interval.

For the upper west and lower west lagoon areas, the same approach was used; however, the unsaturated zone is estimated to extend to depths of 7.5 feet and 5 feet, respectively. Therefore, only the 2-foot and 5-foot sampling results were relied upon to determine soil concentrations in the designated area (i.e., the area of the site where total VOC soil concentrations exceed 1,000 mg/kg). This methodology was applied to each of the three sub-areas for the chemicals of potential concern, resulting in the soil concentrations presented in Table A-2.

2. Disturbance of Surficial Soils

For certain soil handling components (i.e., grading) of the remedial alternatives, soil moving activities will largely be limited to the upper two feet of soil. Average and reasonable maximum soil concentrations in the three sub-areas of the site: lower west, upper west, and upper east lagoons, were estimated based on the arithmetic mean and 95 percent upper confidence limit (UCL) of the mean of samples collected at 3 inches and 1.5 feet during the 1993 surficial soil sampling episode. Samples collected at three inches were considered to be representative of concentrations between the ground surface and one foot. Samples collected at a depth of 1.5 feet would be representative of concentrations in the soil interval between one and two feet below ground surface (bgs). The average and 95 percent UCL concentrations for both soil intervals were averaged to estimate average and reasonable maximum soil concentrations, respectively. It should be noted that in cases where a chemical of potential concern was not detected, a concentration equal to one-half the detection limit was used. Concentrations of the chemicals of potential concern estimated using this methodology are presented in Table A-3.

B. Soil Concentrations Applicable to Passive Diffusion

Although, theoretically, passive diffusion emissions can occur from surficial soils, the primary source of passive diffusion emissions will be the underlying, highly contaminated soil, generally present below a depth of 3.5 feet. Below this depth within the former lagoon areas, sampling has indicated that contaminants are present in the form of DNAPLs, which provide a constant and relatively non-depleting source of emissions.

The DNAPL-containing areas of the site represent a significantly greater source of emissions than areas without DNAPLs, where concentrations are relatively low. It is estimated that DNAPL is likely present when total VOC concentrations exceed 1,000 mg/kg.

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TABLE A-2			
Estimated Average and Reasonable Maximum Soil Concentrations			
for Soil with Total VOC Concentrations in Excess of 1000 mg/kg			
Chemicals of Potential Concern	**Average Concentration (mg/kg)**		
	Lower West	**Upper West**	**Upper East**
1,2,3-Trichloropropane	1,102	3,359	1,982
Trichloroethene	5.7	22.5	52.1
Benzene	4.5	17.7	49.1
Tetrachloroethene	57.9	728	100
Toluene	575	173	1,103
Ethylbenzene	650	1,129	661
Xylenes	5,502	7,255	3,783
Chemicals of Potential Concern	**Reasonable Maximum Concentration (mg/kg)**		
	Lower West	**Upper West**	**Upper East**
1,2,3-Trichloropropane	4,311	7,127	3,456
Trichloroethene	20.4	42.8	110
Benzene	16.5	36.4	107
Tetrachloroethene	225	1,529	198
Toluene	2,254	377	2,118
Ethylbenzene	2,548	2,339	1,302
Xylenes	21,559	15,326	6,622

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TABLE A-3 Estimated Average and Reasonable Maximum Soil Concentrations for the Uppermost Two Feet of Soil				
Chemicals of Potential Concern	**Average Concentration (mg/kg)**			
	Lower West	Upper West	Upper East	Lower East[a]
1,2,3-Trichloropropane	0.29	45.8	37.8	0.0055
Trichloroethene	0.005	2.5	1.9	0.0055
Benzene	0.005	2.5	1.9	0.0055
Tetrachloroethene	0.005	2.5	2.8	0.0055
Toluene	0.005	2.5	2.3	0.0055
Ethylbenzene	0.005	2.5	7.5	0.0055
Xylenes	0.006	20.8	55.4	0.0055
Chemicals of Potential Concern	**Reasonable Maximum Concentration (mg/kg)**			
	Lower West	Upper West	Upper East	Lower East[a]
1,2,3-Trichloropropane	0.97	136.8	89.5	0.0055
Trichloroethene	0.006	7.2	4.8	0.0055
Benzene	0.006	7.2	4.8	0.0055
Tetrachloroethene	0.006	7.2	7.5	0.0055
Toluene	0.006	7.2	5.7	0.0055
Ethylbenzene	0.006	7.2	20.2	0.0055
Xylenes	0.007	56.5	146.9	0.0055
a - Half the detection limit				

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The areas of the Tyson's site where DNAPL is estimated to exist, therefore, are shown in Figures A-1 and A-2. As discussed earlier, based on the total VOC contours developed by ERM, soil samples collected with the 1,000 mg/kg tot VOC contour were selected for use in this analysis. Samples in this area were used to estimate concentrations in these highly contaminated areas. Estimates of average and reasonable maximum DNAPL-area soil concentrations were based on the arithmetic mean and the 95 percent UCL of the mean, respectively, of samples collected in the soil horizon expected to be the principal source of vapor emissions (i.e., between 3.5 feet and 7.5 feet). Concentrations of chemicals of potential concern in areas outside the DNAPL-containing areas (i.e., with total VOC concentrations < 1,000 mg/kg) were similarly estimated. Tables A-4 and A-5 summarize the estimated soil concentrations for the DNAPL and non-DNAPL areas of the site, respectively.

C.   Soil Concentrations Applicable to Direct Soil Contact

To estimate exposure due to direct contact with soil after implementation of the remedial alternative, soil concentrations in surficial soils were estimated based on surficial soil sampling (ERM 1993). Average and reasonable maximum soil concentrations of the chemicals of potential concern were estimated for the four sub-areas of the site (upper west, lower west, upper east, and lower east lagoons areas) based on the arithmetic average and the 95 percent UCL of the mean of samples collected at three inches during the 1993 sampling episode. It should be noted that in cases where a chemical of potential concern was not detected, a concentration equal to one-half the detection limit was used. Average and reasonable maximum surficial soil concentrations are presented in Table A-6. As expected, due to their volatile nature, concentrations of the constituents of concern in surficial soils are extremely low.

For the off-site incineration alternative, surficial soil samples from those areas where excavation would not occur were used to estimate direct contact soil concentrations. Surficial soil concentrations used to estimate direct contact risks for the off-site incineration alternative are shown in Table A-7.

D.   Residual Soil Concentrations in LTTD-Treated Soil

During excavation associated with the LTTD treatment alternative, soil concentrations of chemicals of potential concern will be reduced somewhat due to soil excavation, handling, and processing activities. In fact, the more volatile compounds, such as benzene and TCE, which are present at relatively low concentrations, are almost entirely removed during these processes. Treatment in the LTTD unit will reduce concentrations further; however, residual
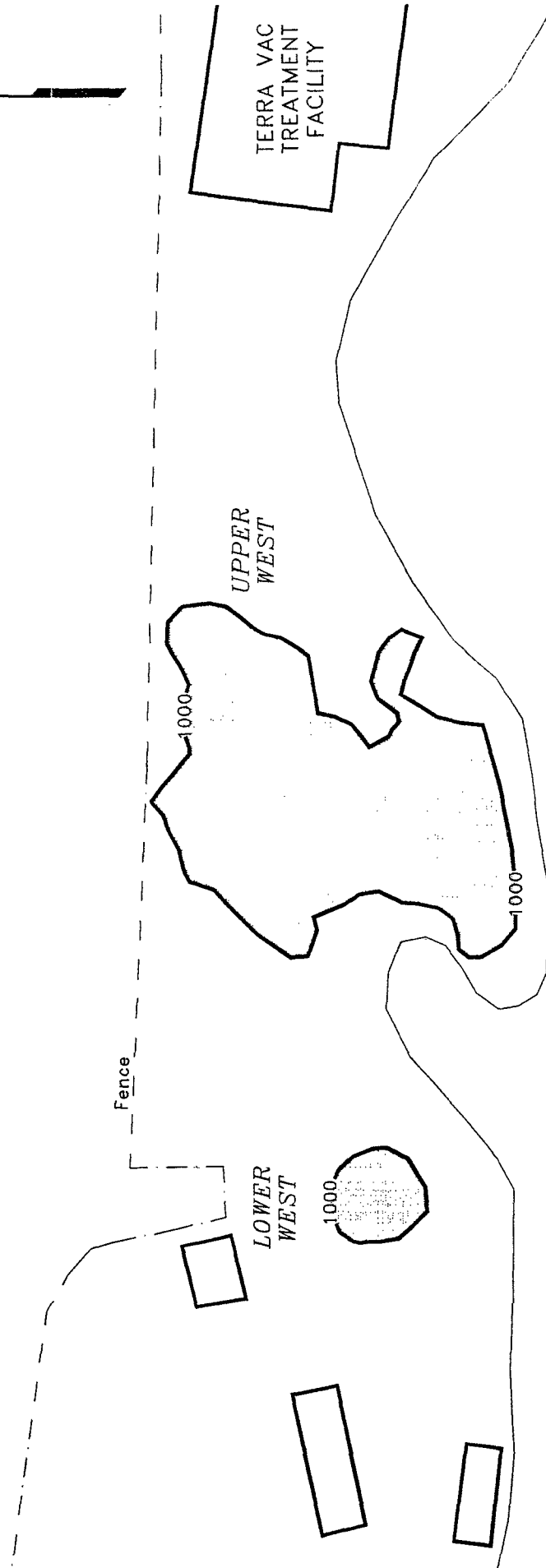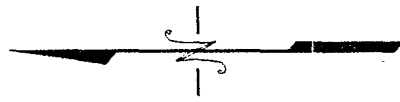
E N V I R O N

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TERRA VAC
TREATMENT
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N

UPPER
WEST

1000

1000

Fence

LOWER
WEST

1000

EXPLANATION

—1000— Value represents TCP concentration in mg/kg at 5 feet

0   60   120

Scale in Feet

c:\acad\01339IA\1339IAB7

Figure
A–1

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DNAPL–CONTAINING AREAS OF THE WEST LAGOON

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DNAPL-CONTAINING AREAS OF THE EAST LAGOON

UPPER EAST

LOWER EAST

Fence

1000

1000

Scale in Feet

0   60   120

EXPLANATION

—1000— Value represents TCP concentration in mg/kg at 5 feet

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Figure A-2
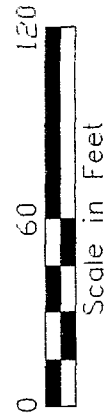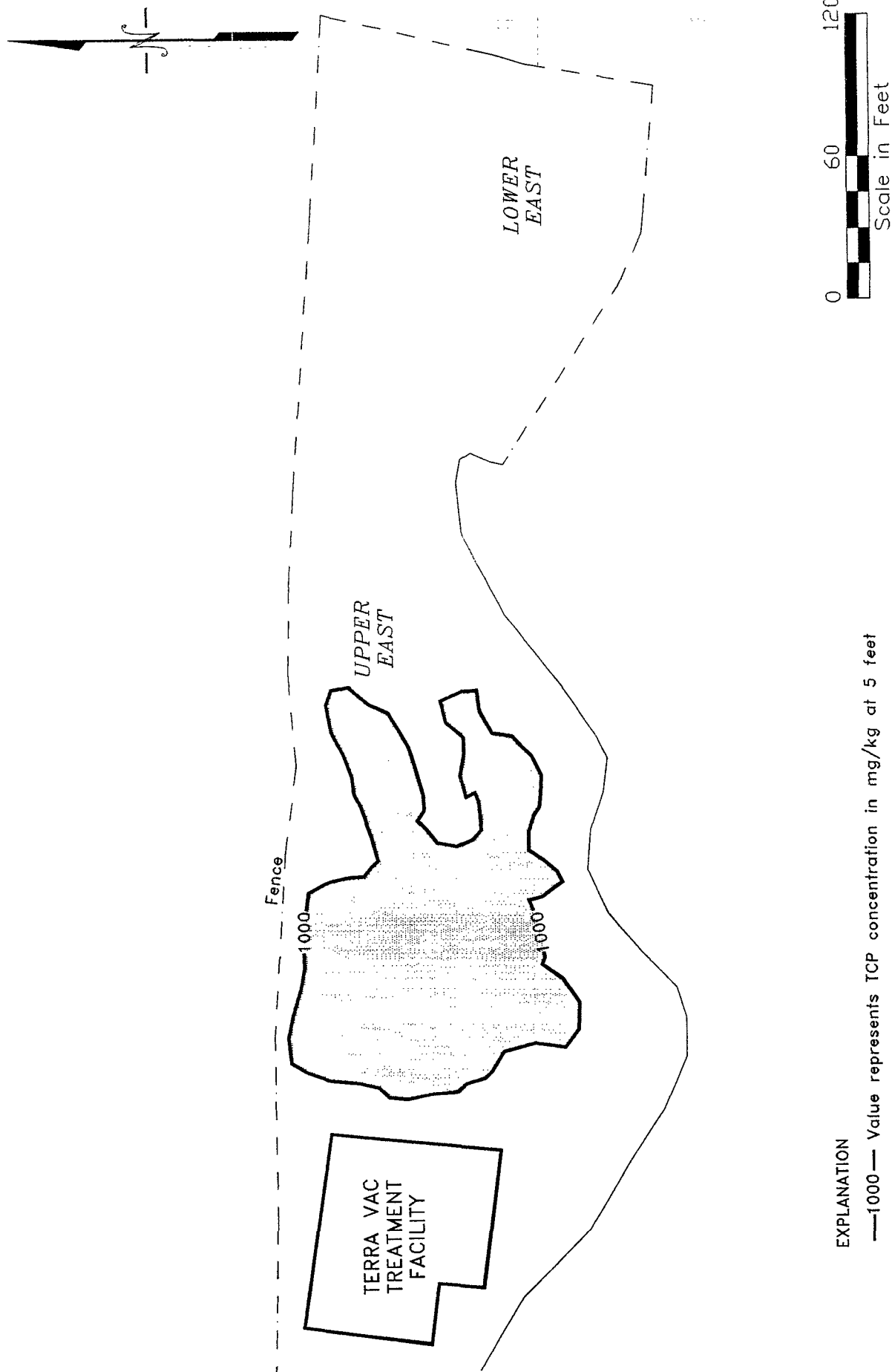
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TABLE A-4 Estimated Soil Concentrations for DNAPL-Containing Areas (Passive Diffusion)			
Chemicals of Potential Concern	Average Concentration (mg/kg)		
	Lower West	Upper West	Upper East
1,2,3-Trichloropropane	3,673	6,218	2,335
Trichloroethene	18.7	38	69
Benzene	15.3	29	66
Tetrachloroethene	193	1,360	154
Toluene	1,917	321	1,793
Ethylbenzene	2,168	2,112	932
Xylenes	18,339	13,759	4,537
Chemicals of Potential Concern	Reasonable Maximum Concentration (mg/kg)		
	Lower West	Upper West	Upper East
1,2,3-Trichloropropane	14,370	13,126	4,964
Trichloroethene	68.1	68	159
Benzene	55.0	56	156
Tetrachloroethene	751	2,855	324
Toluene	7,513	694	3,781
Ethylbenzene	8,493	4,374	2,089
Xylenes	71,864	28,649	10,087

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TABLE A-5 Estimated Average and Reasonable Maximum Soil Concentrations for Non-DNAPL Containing Areas			
Chemicals of Potential Concern	**Average Concentration (mg/kg)**		
	Lower West	Upper West	Upper East
1,2,3-Trichloropropane	1.4	18.1	3.6
Trichloroethene	0.8	1.6	0.9
Benzene	0.8	1.6	0.9
Tetrachloroethene	0.8	1.7	1.3
Toluene	0.8	1.6	5.6
Ethylbenzene	0.8	2.3	4.2
Xylenes	0.8	12.1	24.2
Chemicals of Potential Concern	**Reasonable Maximum Concentration (mg/kg)**		
	Lower West	Upper West	Upper East
1,2,3-Trichloropropane	2.2	40.3	6.5
Trichloroethene	1.1	2.4	1.2
Benzene	1.1	2.5	1.2
Tetrachloroethene	1.1	2.6	2.0
Toluene	1.1	2.5	13.5
Ethylbenzene	1.1	4.4	9.4
Xylenes	1.1	29.9	56.1

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TABLE A-6 Estimated Average and Reasonable Maximum Surficial Soil Concentrations (Direct Contact Exposure)				
Chemicals of Potential Concern	**Average Concentration (mg/kg)**			
	Lower West	Upper West	Upper East	Lower East[a]
1,2,3-Trichloropropane	0.46	0.71	5.6	0.0055
Trichloroethene	0.005	0.12	0.38	0.0055
Benzene	0.005	0.12	0.38	0.0055
Tetrachloroethene	0.005	0.13	1.2	0.0055
Toluene	0.005	0.12	0.59	0.0055
Ethylbenzene	0.005	0.12	0.81	0.0055
Xylenes	0.006	4.4	6.0	0.0055
Chemicals of Potential Concern	**Reasonable Maximum Concentration (mg/kg)**			
	Lower West	Upper West	Upper East	Lower East[a]
1,2,3-Trichloropropane	1.51	1.7	12.1	0.0055
Trichloroethene	0.006	0.35	0.68	0.0055
Benzene	0.006	0.35	0.68	0.0055
Tetrachloroethene	0.006	0.39	2.8	0.0055
Toluene	0.006	0.35	1.1	0.0055
Ethylbenzene	0.006	0.35	1.5	0.0055
Xylenes	0.008	13.2	11.1	0.0055

a - Half the detection limit

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TABLE A-7
Estimated Average and Reasonable Maximum Soil Concentrations for
Surficial Soils After Implementation of the Off-Site Incineration Alternative

Chemicals of Potential Concern	Average Concentration (mg/kg)	Reasonable Maximum Concentration (mg/kg)
1,2,3-Trichloropropane	0.044	0.108
Trichloroethene	0.005	0.006
Benzene	0.005	0.006
Tetrachloroethene	0.005	0.006
Toluene	0.005	0.006
Ethylbenzene	0.005	0.006
Xylenes	0.005	0.006

concentrations of chemicals of potential concern may remain in the soil after treatment and be returned to the lagoon areas as backfill material.

      To estimate residual concentrations in soil treated in the LTTD unit, a mass balance approach was used to represent volatile losses during excavation, processing, and LTTD treatment. Emission rates of chemicals of potential concern were estimated (as described in the following chapter) for the excavation, soil processing, and LTTD treatment operations. After each step in the process, the concentration of chemicals of potential concern was recalculated based on the initial concentration and the estimated emission rate. For example, the concentration of contaminants in soil fed to the LTTD treatment unit were reduced from *in-situ* soil concentrations due to excavating, transferring to a dump truck, and crushing and screening inside the enclosure. After estimating VOC losses during LTTD treatment, assuming a 99 percent LTTD removal efficiency and using methods prescribed by EPA (1993), the residual concentrations in treated soil, which is used as backfill in the excavated areas of the site, were estimated. Estimated residual soil concentrations are presented in Table A-8.

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TABLE A-8 Estimated Average and Reasonable Maximum Residual Soil Concentrations After LTTD Treatment			
Chemicals of Potential Concern	**Average Concentration (mg/kg)**		
	Lower West	**Upper West**	**Upper East**
1,2,3-Trichloropropane	10.3	32.3	18.8
Trichloroethene	2.0×10^{-2}	7.7×10^{-3}	1.8×10^{-2}
Benzene	1.3×10^{-3}	5.0×10^{-3}	1.4×10^{-2}
Tetrachloroethene	6.2×10^{-3}	5.5	3.1×10^{-1}
Toluene	4.2	8.7×10^{-1}	9.0
Ethylbenzene	5.6	10.1	5.7
Xylenes	52.8	71.0	35.9
Chemicals of Potential Concern	**Reasonable Maximum Concentration (mg/kg)**		
	Lower West	**Upper West**	**Upper East**
1,2,3-Trichloropropane	41.7	69.5	33.3
Trichloroethene	7.0×10^{-3}	1.5×10^{-2}	3.8×10^{-2}
Benzene	4.6×10^{-3}	1.0×10^{-2}	4.6×10^{-2}
Tetrachloroethene	1.2	12.8	1.0
Toluene	19.7	2.5	18.4
Ethylbenzene	23.8	21.8	11.8
Xylenes	211	150	63.8

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U.S. Environmental Protection Agency (USEPA). 1993. *Air/Superfund national technical guidance series. Models for estimating air emission rates from Superfund remedial actions.* Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-451/R-93-001. March.

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APPENDIX B

Estimation of Emission Rates

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APPENDIX B: ESTIMATION OF EMISSION RATES

Emissions from the former lagoon areas may occur in the form of particulates or vapors during both implementation and after completion of the remedy. Given the volatility of the chemicals involved, the control measures normally instituted to suppress particulate generation, and the distance to the property boundary, vapor emissions are anticipated to be the principal contributor to risk, so particulate emissions are not evaluated quantitatively in this assessment. Vapor emissions at the site occur as a result of increased volatilization during excavation and passive diffusion of DNAPL constituent vapors in the subsurface environment. Even under circumstances where DNAPL-containing soils are removed or remediated, passive diffusion of vapors will still occur from DNAPL in ground water and in the bedrock underlying the site. This upward diffusion will cause recontamination of the overlying soils and will provide a continuing source of emissions from the site (AGRL 1994).

To quantify inhalation exposures in the site vicinity, it is first necessary to estimate emission rates of chemicals from soil to the atmosphere. Several vapor emissions models were compiled as described in the following sections, and were used to develop chemical-specific emission rates.

A.   Excavation/Soil Handling Vapor Emission Models

EPA has developed models for estimating emissions from excavation and earth-moving activities (USEPA 1992), based on two types of emissions: pore space emissions and diffusion emissions from freshly exposed soil. These emissions are a function of time, t, as indicated in the following equation:

$$ER_{tot}(t) = ER_{ps} + ER_{diff}(t) \tag{B-1}$$

where,

$ER_{tot}(t)$	=	total chemical emission rate due to excavation activities, g/sec
ER_{ps}	=	chemical emission rate from soil pore spaces, g/sec
$ER_{diff}(t)$	=	chemical emission rate due to diffusion, g/sec

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The procedures described in the EPA (1992) report are qualified as providing rough, worst-case estimates of emissions with very limited validation. Consequently, these models should be viewed as providing only order-of-magnitude estimates.

Pore space emissions involve the release of volatile compounds from the soil pore space when the soil is disturbed. The model suggested by EPA assumes that one-third of the volatile compounds in the pore space air are released with each soil movement during active excavation. To estimate the amount of chemical released during excavation, it is necessary to estimate both the total volume of available pore space in the excavated soil and the concentration of chemical in the pore space air. The emission rate from soil pore space during excavation is estimated using the following equation (USEPA 1992):

$$ER_{ps} = \frac{VP\ MW\ (10^6\ cm^3/m^3)\ \theta_a\ Q\ ExC}{R\ T} \qquad \text{(B-2)}$$

where,

ER_{ps}	=	chemical emission rate from soil pore spaces, g/sec
VP	=	vapor pressure, mm Hg (Table B-1)
MW	=	molecular weight, g/g-mol (Table B-1)
θ_a	=	air-filled porosity of soil, unitless (Table B-2)
Q	=	excavation rate, m³/sec (Chapter IV)
ExC	=	vapor exchange constant, unitless (0.333)
R	=	gas constant, mm Hg cm³/g-mol K (62,361)
T	=	temperature, K (298)

It should be noted that equation (B-2) is based on the assumption that the soil pore space is saturated with the compound being emitted. If this is not the case, then equation (B-2) may overpredict the emission rate from the soil pore space. To compensate for this potential source of overprediction, pore space emissions estimated in equation (B-2) are limited to one-third of the total available mass that may be emitted from the soil.

The pore space emissions model requires as inputs both chemical-specific parameters, such as vapor pressure and molecular weight, and site-specific parameters, such as air-filled porosity of the soil and excavation rate. Summaries of the chemical-specific and the site-specific parameters used in the pore space emissions model are provided in Tables B-1 and B-2, respectively.

The second type of emissions, diffusion emissions, occur from soil that is freshly

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Table B-1

Chemical-Specific Parameters Used in Fate and Transport Modeling

Compound	Molecular Weight (g/mol)	Vapor Pressure[m] (mm Hg)	Air Diffusion Coefficient[e] (cm²/s)	Henry's Constant (H')[n] (unitless)	Henry's Constant (H) (atm m³/mol)	Koc	Solubility in Water (mg/L)	Diffusion Coefficient in Water (cm²/sec)
1,2,3-Trichloropropane	147.4	3	0.0730[d]	0.0167	4.09×10^{-4}[f]	72[a]	1,900	7.8×10^{-6}
Xylenes	106.2	8	0.0738	0.288	7.05×10^{-3}[a]	240[b]	200	8.4×10^{-6}
Ethylbenzene	106.2	10	0.0687	0.263	6.43×10^{-3}[a]	1100[a,c]	135	8.3×10^{-6}
Toluene	92.1	30	0.0807	0.261	6.38×10^{-3}[a]	300[a,c]	580	9.0×10^{-6}
Tetrachloroethene	165.8	19	0.0763	0.753	1.84×10^{-2}[a]	363[h]	240	9.3×10^{-6}
Trichloroethene	131.4	75	0.0836	0.421	1.03×10^{-2}[a]	104[i]	1,380	7.8×10^{-6}
Benzene	78	95	0.0897	0.227	5.55×10^{-3}[j]	49[k]	1,780	8.5×10^{-6}

Values are for 25°C unless otherwise noted.

a - CONCAWE (1979). Protection of Groundwater from Oil Pollution. As cited in U.S. Environmental Protection Agency (1990). Basics of Pump-and-Treat Ground-Water Remediation Technology. EPA/600/8-90/003.

b - Payne, J.R. and C.R. Phillips (1985). Petroleum spills in the marine environment, Lewis Publishers, Chelsea, MI. As cited in U.S. Environmental Protection Agency (1990). Basics of Pump-and-Treat Ground-Water Remediation Technology. EPA/600/8-90/003.

c - Shen, T. (1981) Estimating hazardous air emissions from disposal sites. Pollution Engineering 13(8):31-4. As cited in U.S. Environmental Protection Agency. (1988). Superfund Exposure Assessment Manual. OSWER Directive 9285.5-1. (value for 30° C).

d - AGRL 1987.

e - Mabey, W.R. et al. (1982). Aquatic fate process data for organic priority pollutants. Prepared by SRI International for Office of Water Regulations and Standards, USEPA, Washington, D.C.

f - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). Calculated by SRC based on VP/Water Sol.

g - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). Calculated using equation 4-5 in Lyman, W.J. et al. (1982)

h - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). Karickoff, S.W. (1981) Semi-empirical estimation of sorption of hydrophobic pollutants on natural sediments and soils. Chemosphere 10:833-46.

i - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). Munz, C. and P.V. Roberts (1987). Air-Water Phase Equilibria of Volatile Organic Solutes. J. Am. Water Works. Assoc. 79:62-9.

j - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). MacKay, D., et al. (1979) Determination of air-water Henry's Law constants for hydrophobic pollutants. Env. Sci. Technol. 13: 333-336.

k - Syracuse Research Corporation 1988 (on-line CHEMFATE data base). Abdul, A.S., et al. (1987) Statistical correlations for predicting the partition coefficient for non-polar organic contaminants between aquifer organic carbon and water. Haz. Waste Haz. Mat. 4:211-22.

l - Howard, P. (1990). Handbook of environmental fate and exposure data for organic chemicals. Volume II. Lewis Publishers, Chelsea, Michigan.

m - U.S. Environmental Protection Agency (1992). Air/Superfund national technical guidance study series: Estimation of air impacts for excavation of contaminated soil. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA 450/1-92-004.

n - Calculated: H' = H/RT; where RT = (8.205x10⁻⁵ atm m³/mol K)(298.15 K)

TABLE B-2 Summary of Site-Specific Parameters Used to Estimate Chemical Vapor Emissions During Excavation/Soil Handling Activities	
Parameter	**Average Value[a]**
Air-filled Porosity, unitless	0.35
Total Soil Porosity, unitless	0.55
Bulk Soil Density (ex-situ, wet soil), g/cm^3	1.4
Fraction of Organic Carbon (f_{oc})	0.01
Wind Speed, m/sec	4.25[b]

Notes:
a - Consistent with EPA guidance (1992a) or site-specific data.
b - Based on meteorological data collected at Philadelphia International Airport
National Weather Service station (NOAA 1985).

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exposed to the atmosphere and is dependent on the time period the soil is exposed. Emissions from freshly exposed soil will initially occur at significantly elevated rates over undisturbed soil, but with the passage of time (several days to weeks) will reach an emission rate equal to the rate of undisturbed soil. The diffusion emissions model suggested by EPA is based on several site-specific parameters, including exposed surface area, time period between soil exposing events, and air porosity, as follows (USEPA 1992):

$$ER_{diff}(t) = \frac{C_s \ (10^4 \ cm^2/m^2) \ SA}{\left(\dfrac{\theta_a}{K_{eq} \ k_g}\right) + \left(\dfrac{\pi \ t}{D_e \ K_{eq}}\right)^{1/2}} \qquad (B-3)$$

where,

$ER_{diff}(t) =$		chemical emission rate due to diffusion, g/sec
C_s	$=$	concentration of chemical in soil, g/cm^3
SA	$=$	surface area of emissions, m^2
K_{eq}	$=$	equilibrium coefficient, unitless
k_g	$=$	gas-phase mass transfer coefficient, cm/sec
t	$=$	time following soil disturbance, sec
D_e	$=$	effective diffusivity in air, cm^2/sec
θ_a	$=$	air-filled porosity of the soil, unitless

and,

$$D_e = D_a \ \frac{\theta_a^{10/3}}{\theta_t^2} \qquad (B-4)$$

where,

D_a	$=$	diffusivity in air, cm^2/sec
θ_t	$=$	total porosity of soil, unitless
θ_a	$=$	air-filled porosity of the soil, unitless

Equation (B-3) is a prediction of the instantaneous emission rate due to diffusion. To estimate the average diffusion emission rate over time between subsequent disturbances (t_d), equation (B-3) was integrated over a time period of t_d, resulting in the following equation for the average diffusion emission rate:

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$$ER_{diff}(t_d) = \frac{2\,C_s\,10^4\,SA}{t_d}\left[\sqrt{\frac{D_e\,K_{eq}\,t_d}{\pi}} - \frac{D_e\,\theta_a}{\pi\,k_g}\ln\left(\frac{K_{eq}\,k_g}{\theta_a}\sqrt{\frac{\pi\,t_d}{D_e\,K_{eq}}} + 1\right)\right] \quad \text{(B-5)}$$

and,

$$k_g = 4.82\,(10^{-3})\,U^{0.78}\,Sc_G^{-0.67}\,de^{-0.11} \quad \text{(B-6)}$$

$$Sc_G = \frac{\mu_a}{\rho_a\,D_a} \quad \text{(B-7)}$$

$$de = \left(\frac{4\,SA}{\pi}\right)^{1/2} \quad \text{(B-8)}$$

$$K_{eq} = \frac{VP\,MW\,\theta_a}{R\,T\,C_s} \quad \text{(B-9)}$$

where,

k_g	=	gas-phase mass transfer coefficient, m/sec (Equation B-6)
U	=	wind speed, m/sec (Table B-2)
Sc_G	=	Schmidt number (gas phase), unitless (Equation B-7)
de	=	effective diameter of emitting area, m (Equation B-8)
μ_a	=	viscosity of air, g/cm-sec (1.81×10^{-4})
ρ_a	=	density of air, g/cm³ (1.2×10^{-3})
D_a	=	diffusivity in air, cm²/sec (Table B-1)
SA	=	surface area of emissions, m² (Chapter IV)
C_s	=	chemical concentration in soil, g/cm³ (Appendix A)
K_{eq}	=	equilibrium coefficient, unitless (Equation B-9)
VP	=	vapor pressure, mm Hg (Table B-1)
MW	=	molecular weight, g/g-mol (Table B-1)
θ_a	=	air-filled porosity of soil, unitless (Table B-2)
R	=	gas constant, mm Hg cm³/g-mol K (62,361)
T	=	temperature, K (298)
t_d	=	time between subsequent disturbances, sec (Chapter IV)

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D_e = effective diffusivity in air, cm^2/sec (Equation B-4)

According to EPA guidance on the use of the excavation emissions model, the value of K_{eq} (equation B-9) should not exceed a value of 1.0, which occurs when concentrations are low so that the constituent is primarily present in the air phase. Therefore, if equation (B-9) results in a K_{eq} greater than 1.0, a value of 1.0 was used. Summaries of the chemical-specific parameters and the site-specific parameters used in the excavation diffusion emissions model are provided in Tables B-1 and B-2, respectively. Values for other parameters are provided in Chapter IV of the risk assessment and in Appendix A, as indicated above.

It should be noted that due to the approximate nature of the excavation emission equations, various checks to verify the results were performed as points of comparison. For example, the total emissions from the site cannot exceed the amount of chemical present. Furthermore, emissions of volatile constituents such as benzene or toluene may exceed 50 percent of the available mass, but emissions of low volatile constituents such as TCP would reasonably be expected to be lower, likely in the range of 5 to 25 percent of the available mass.

Estimated emission rates (grams/second) for soil handling and excavation activities are summarized in Tables B-3 to B-5. Tables B-3 and B-4 summarize the estimated emission rates due to active excavation and dumping soil into a dump truck, respectively. Estimated emission rates associated with surficial soil handling activities (grading) are presented in Table B-5.

B. Passive Diffusion Vapor Emission Models

Two methods were used to estimate volatile emissions from soils at the site, depending on the type and duration of the passive diffusion emissions source. For passive diffusion emissions occurring over a short period of time, an unsteady-state vapor emissions model was applied. For long-term emissions, a steady-state diffusion model was used. A description of the models used is provided below.

1. Short-Term Passive Diffusion

During remedy implementation, after the SVE system has been removed from operation and before completion of the remedy, short-term (less than one year) passive diffusion emissions may occur. As noted earlier, the primary source for these emissions is the high-concentration, DNAPL-containing zone primarily present below

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TABLE B-3
Estimated Emission Rates Due to Active Excavation of Soil with Total VOC Concentrations in Excess of 1,000 mg/kg (Off-site Incineration/Disposal and On-site LTTD Treatment Alternatives)

Chemical	Average Flux (g/sec)		
	Lower West	Upper West	Upper East
Benzene	2.20×10^{-2}	8.67×10^{-2}	2.40×10^{-1}
Ethylbenzene	2.73×10^{-1}	3.50×10^{-1}	2.75×10^{-1}
Toluene	4.78×10^{-1}	2.96×10^{-1}	6.33×10^{-1}
Tetrachloroethene	6.82×10^{-2}	5.56×10^{-1}	2.59×10^{-1}
Trichloroethene	2.78×10^{-1}	1.08×10^{-1}	2.50×10^{-1}
1,2,3-Trichloropropane	2.22×10^{-1}	3.74×10^{-1}	2.92×10^{-1}
Xylenes	6.70×10^{-1}	7.68×10^{-1}	5.62×10^{-1}

Chemical	Reasonable Maximum Flux (g/sec)		
	Lower West	Upper West	Upper East
Benzene	8.08×10^{-2}	1.78×10^{-1}	4.99×10^{-1}
Ethylbenzene	5.09×10^{-1}	4.89×10^{-1}	3.73×10^{-1}
Toluene	8.70×10^{-1}	4.01×10^{-1}	8.46×10^{-1}
Tetrachloroethene	3.47×10^{-1}	7.66×10^{-1}	3.31×10^{-1}
Trichloroethene	9.78×10^{-2}	2.05×10^{-1}	5.27×10^{-1}
1,2,3-Trichloropropane	4.21×10^{-1}	5.33×10^{-1}	3.79×10^{-1}
Xylenes	1.27	1.09	7.31×10^{-1}

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TABLE B-4
Estimated Emission Rates Due to Dumping Excavated Soils into Dump Truck
(Off-site Incineration/Disposal and On-Site LTTD Treatment Alternatives)

Chemical	Average Flux (g/sec)		
	Lower West	Upper West	Upper East
Benzene	2.25×10^{-3}	8.84×10^{-3}	2.45×10^{-2}
Ethylbenzene	1.08×10^{-1}	1.33×10^{-1}	1.09×10^{-1}
Toluene	2.02×10^{-1}	1.38×10^{-1}	2.55×10^{-1}
Tetrachloroethene	8.75×10^{-3}	2.35×10^{-1}	1.29×10^{-1}
Trichloroethene	3.15×10^{-2}	1.23×10^{-2}	2.84×10^{-2}
1,2,3-Trichloropropane	8.00×10^{-2}	1.26×10^{-1}	1.02×10^{-1}
Xylenes	2.29×10^{-1}	2.58×10^{-1}	1.96×10^{-1}

Chemical	Reasonable Maximum Flux (g/sec)		
	Lower West	Upper West	Upper East
Benzene	8.24×10^{-3}	1.82×10^{-2}	6.60×10^{-2}
Ethylbenzene	1.84×10^{-1}	1.78×10^{-1}	1.41×10^{-1}
Toluene	3.34×10^{-1}	1.76×10^{-1}	3.26×10^{-1}
Tetrachloroethene	1.62×10^{-1}	3.06×10^{-1}	1.56×10^{-1}
Trichloroethene	1.11×10^{-2}	2.33×10^{-2}	5.99×10^{-2}
1,2,3-Trichloropropane	1.40×10^{-1}	1.72×10^{-1}	1.28×10^{-1}
Xylenes	4.00×10^{-1}	3.48×10^{-1}	2.47×10^{-1}

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TABLE B-5		
Estimated Emission Rates Due to Surficial Soil Handling Activities (Grading)		
Chemical	Average Emission Rate (g/sec)	Reasonable Maximum Emission Rate (g/sec)
Benzene	1.30×10^{-2}	2.66×10^{-2}
Ethylbenzene	3.09×10^{-2}	7.14×10^{-2}
Toluene	1.41×10^{-2}	2.84×10^{-2}
Tetrachloroethene	1.56×10^{-2}	3.33×10^{-2}
Trichloroethene	1.27×10^{-2}	2.60×10^{-2}
1,2,3-Trichloropropane	7.59×10^{-2}	1.00×10^{-1}
Xylenes	1.16×10^{-1}	1.57×10^{-1}

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a depth of 3.5 feet. When the SVE system is removed, vapor in the air-filled pore space previously removed by the SVE system will begin to diffuse upward through the less contaminated, overlying soil to the atmosphere. Because this upward diffusion process is slow, it is unlikely that a steady-state emission rate will be attained during the brief period (approximately 80 days) between SVE removal and completion of the remedy (applies only to the non-excavation alternatives). Therefore, to estimate volatile emissions due to passive diffusion during this period, an unsteady-state vapor diffusion model developed by EPA (1986) was used. This unsteady-state model accounts for the presence of clean soil overlying the contaminated soil zone. The equation used to calculate the flux is presented below:

$$J_{st} = \frac{8\left(\frac{H}{K_d}\right)C_s D_e d_c}{\alpha \pi^2 t_a} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2}\left[1 - e^{\frac{-\alpha(2n+1)^2\pi^2 t_a}{4d_c^2}}\right]\cos\left[\left(\frac{2n+1}{2}\right)\left(\frac{\pi L}{d_c}\right)\right] \quad \text{(B-10)}$$

and,

$$\alpha = \frac{D_e}{\theta_a + \frac{\theta_t - \theta_a}{H} + \frac{\rho K_d(1 - \theta_t)}{H}} \quad \text{(B-11)}$$

where,

J_{st}	=	short-term chemical flux, g/sec-cm^2
d_c	=	depth of contaminated soil, cm (610)
t_a	=	averaging period of emissions, sec (estimated duration of implementation; Chapter IV)
L	=	diffusion distance, cm (Table B-6)
ρ	=	bulk density of soil, g/cm^3 (Table B-6)
K_d	=	soil/water partition coefficient, mL/g (Equation B-12)
H	=	Henry's Law constant, unitless (Table B-1)
C_s	=	concentration of chemical in soil, mg/kg (Appendix A)
D_e	=	effective diffusivity in air, cm^2/sec (Equation B-4)
θ_a	=	air-filled porosity of the soil, unitless (Table B-6)
θ_t	=	total porosity of soil, unitless (Table B-6)

and,

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$$K_d = K_{oc} f_{oc} \qquad \text{(B-12)}$$

where,

K_{oc} = organic carbon partition coefficient, mL/g (Table B-1)

f_{oc} = fraction of organic carbon in soil, unitless (Table B-6)

Although this equation represents a reasonable attempt to simulate conditions immediately following cessation of the SVE system, inherent limitations in the model prevent an accurate representation of conditions; consequently, emissions are likely to be overestimated. Nonetheless, for remedies involving excavation, emissions from short-term passive diffusion are not expected to be significant as compared with active emissions.

A summary of the chemical-specific parameters used in the short-term passive diffusion model is provided in Table B-1. Site-specific parameters for *in-situ* soil are shown in Table B-6. Estimated flux rates due to short-term passive diffusion are summarized in Table B-7.

2. Long-Term Diffusion

Passive diffusion of chemicals in subsurface soils after implementation of the remedy is expected to occur over a long duration; therefore, it is likely that a steady-state emission rate is a reasonable approximation of average emissions over time. A steady-state vapor emission model suggested by EPA (1988) was used to estimate long-term passive diffusion emissions. Two variations of the model were used; one variation provides a prediction of diffusion through water-filled pore space (i.e., water saturated pore space, as expected with a saturated clay cap), the other through air-filled pore space (as expected with overlying soil cover).

a. Passive Diffusion Through a Saturated Clay Cap

To estimate steady-state emissions of volatile constituents through a saturated clay cap, the following model was used:

$$J_{lt} = D_{ew} \frac{C_w}{L} \qquad \text{(B-13)}$$

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TABLE B-6 Site-Specific Parameters Used to Estimate Passive Diffusion Emissions from DNAPL-Containing Areas		
Parameter	**In-Situ Soil**	**Saturated Clay Layer**
Air-filled Porosity, unitless	0.25	0
Total Soil Porosity, unitless	0.45	0.4
Bulk Soil Density (wet), g/cm^3	1.6	NA
Bulk Soil Density (dry), g/cm^3	1.4	NA
Fraction of Organic Carbon (f_{oc})	0.01	NA
Diffusion Thickness, ft	5.5	2

DNAPL-Containing Soil Surface Area, m^2
    Lower West Lagoon Area
    Upper West Lagoon Area
    East Lagoon Area
	112
	1190
	1360	

Values are based on site data and are generally consistent with EPA guidance (1992a).		

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TABLE B-7 Estimated Flux Rates Due to Short-Term Passive Diffusion Between SVE Removal and Remedy Completion			
Chemical	**Average Flux (g/sec-m^2)**		
	Lower West	**Upper West**	**Upper East**
Benzene	1.05×10^{-6}	2.00×10^{-6}	4.55×10^{-6}
Ethylbenzene	3.19×10^{-9}	3.10×10^{-9}	1.37×10^{-9}
Toluene	4.48×10^{-6}	8.41×10^{-7}	4.48×10^{-6}
Tetrachloroethene	3.37×10^{-6}	1.43×10^{-5}	2.70×10^{-6}
Trichloroethene	1.02×10^{-6}	2.07×10^{-6}	3.77×10^{-6}
1,2,3-Trichloropropane	5.03×10^{-10}	5.03×10^{-10}	5.03×10^{-10}
Xylenes	1.85×10^{-6}	1.85×10^{-6}	1.85×10^{-6}
Chemical	**Reasonable Maximum Flux (g/sec-m^2)**		
	Lower West	**Upper West**	**Upper East**
Benzene	3.79×10^{-6}	3.86×10^{-6}	1.07×10^{-5}
Ethylbenzene	3.51×10^{-9}	3.51×10^{-9}	3.07×10^{-9}
Toluene	4.48×10^{-6}	1.82×10^{-6}	4.48×10^{-6}
Tetrachloroethene	1.31×10^{-5}	1.43×10^{-5}	5.67×10^{-6}
Trichloroethene	3.72×10^{-6}	3.71×10^{-6}	8.68×10^{-6}
1,2,3-Trichloropropane	5.03×10^{-10}	5.03×10^{-10}	5.03×10^{-10}
Xylenes	1.85×10^{-6}	1.85×10^{-6}	1.85×10^{-6}

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where,

J_{lt} = long-term chemical flux, g/sec-cm^2

D_{ew} = diffusion coefficient in pore-space water, cm^2/sec (Equation B-14)

C_w = source concentration of contaminant in pore water, g/cm^3 (Equation B-15)

L = diffusion distance (e.g., thickness of clay cover), cm (Table B-6)

The diffusion coefficient, D_{ew}, is based on the free solution diffusion coefficient, D_o, and the water-filled porosity using the following equation:

$$D_{ew} = D_o \, \theta_w^{4/3} \qquad \text{(B-14)}$$

where,

D_{ew} = diffusion coefficient in pore-space water, cm^2/sec

D_o = free solution diffusion coefficient, cm^2/sec (Table B-1)

θ_w = water-filled porosity, unitless (table B-6)

As noted earlier, the site was divided between areas of low and high concentration, based on the absence or presence of DNAPL. The methodology used to estimate the source concentration, C_w, from these areas differs because in the high-concentration areas containing DNAPL, the pore spaces are saturated with constituents of the DNAPL. In the high-concentration areas (within the 1,000 mg/kg total VOC contour), the source concentration in pore water was estimated as follows:

$$C_w = S_w \, x \, MF_i \qquad \text{(B-15)}$$

where,

C_w = source concentration of contaminant in pore water, g/cm^3

S_w = solubility of chemical in water, mg/L (Table B-1)

MF_i = mole fraction of chemical in DNAPL, unitless (calculated based on estimated soil concentrations; Appendix A)

In areas where the pore space is not saturated with DNAPL (outside the

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1,000 mg/kg total VOC contour), the source concentration of contaminant is based on an estimate of the pore-water concentration at the bottom of the cap and is expressed in terms of the total soil concentration, as follows (Feenstra et al. 1991):

$$C_w = \frac{C_t \rho_d}{K_d \rho_d + \theta_w + H \theta_a} \tag{B-16}$$

where,

C_t	=	total soil concentration, $\mu g/g$ dry weight
ρ_d	=	dry bulk density of soil, g/cm^3 (Table B-6)
K_d	=	soil/water partition coefficient, cm^3/g (Equation B-12)
H	=	Henry's Law constant, unitless (Table B-1)
θ_a	=	air-filled porosity of the soil beneath the cap, unitless (Table B-6)
θ_w	=	water-filled porosity, unitless (Table B-6)

The total soil concentration was conservatively determined, based on soil samples collected between depths of 3.5 feet and 7.5 feet during the 1988 subsurface soil sampling episode (dry-weight), as discussed in Appendix A. Site-specific parameter values that will be used to estimate emissions through the clay cap are presented in Table B-6. Estimated long-term diffusion flux rates through a clay cap are shown in Table B-8.

It should be noted that emission rates from areas where pore space was not saturated with DNAPL were estimated to be insignificant compared to emissions from DNAPL-containing areas. Emissions from these non-DNAPL containing areas, therefore, were not considered further in the risk assessment.

b.   Passive Diffusion Through Overlying Soil

To estimate steady-state passive diffusion emissions through air-filled pore space in soils above the contaminated zone (at 3.5 feet bgs), the following equation was used:

TABLE B-8
Estimated Flux Rates Due to Long-Term Passive Diffusion Through Clay Cap
(Diffusion from DNAPL-containing Areas)

Chemical	Average Flux (g/sec-m²)		
	Lower West	Upper West	Upper East
Benzene	5.96×10^{-10}	1.33×10^{-9}	6.94×10^{-9}
Ethylbenzene	4.60×10^{-9}	5.28×10^{-9}	5.34×10^{-9}
Toluene	2.19×10^{-8}	4.31×10^{-9}	5.51×10^{-8}
Tetrachloroethene	5.23×10^{-10}	4.34×10^{-9}	1.12×10^{-9}
Trichloroethene	3.08×10^{-10}	7.38×10^{-9}	3.07×10^{-9}
1,2,3-Trichloropropane	7.43×10^{-8}	1.48×10^{-7}	1.27×10^{-7}
Xylenes	5.84×10^{-8}	5.16×10^{-8}	3.89×10^{-8}

Chemical	Reasonable Maximum Flux (g/sec-m²)		
	Lower West	Upper West	Upper East
Benzene	5.47×10^{-10}	1.23×10^{-9}	7.51×10^{-9}
Ethylbenzene	4.60×10^{-9}	5.24×10^{-9}	5.48×10^{-9}
Toluene	2.19×10^{-8}	4.46×10^{-9}	5.33×10^{-8}
Tetrachloroethene	5.19×10^{-10}	4.36×10^{-9}	1.08×10^{-9}
Trichloroethene	2.86×10^{-10}	6.32×10^{-10}	3.24×10^{-9}
1,2,3-Trichloropropane	7.42×10^{-8}	1.50×10^{-7}	1.24×10^{-7}
Xylenes	5.84×10^{-8}	5.14×10^{-8}	3.97×10^{-8}

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$$J_{lt} = D_e \frac{C_a}{L}$$ (B-17)

where,

J_{lt} =   long-term chemical flux, g/sec-cm^2

D_e =   effective diffusion coefficient, cm^2/sec (Equation B-18)

C_a =   source concentration of contaminant in air-filled pore space, g/cm^3 (Equation B-19)

L =   diffusion distance (e.g., thickness of overlying soil), cm (Table B-6)

The effective diffusion coefficient, D_e, is based on the diffusion coefficient in air, D_a, the air-filled porosity, and the total porosity, using the following equation:

$$D_e = D_a \frac{\theta_a^{10/3}}{\theta_t^2}$$ (B-18)

where,

D_e =   effective diffusion coefficient, cm^2/sec

D_a =   diffusion coefficient in air, cm^2/sec (Table B-1)

θ_a =   air-filled porosity of the soil, unitless (Table B-6)

θ_t =   total porosity of the soil, unitless (Table B-6)

As noted earlier, the site was divided between areas of low and high concentration. The methodology used to estimate the source concentration, C_a, for the high-concentration areas containing DNAPL is based on Raoult's law. In the high-concentration areas (within the 1,000 mg/kg total VOC contour), the source concentration was estimated as follows:

$$C_a = MF_i \frac{VP_i}{P_s} \frac{MW_i}{V_m}$$ (B-19)

where,

C_a =   source concentration of contaminant in air-filled pore

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space, g/cm³

MF$_i$ = mole fraction of constituent i in the DNAPL, unitless (calculated based on soil concentrations; Appendix A)

VP$_i$ = vapor pressure of constituent i, mm Hg (Table B-1)

P$_s$ = standard atmospheric pressure, mm Hg (760)

MW$_i$ = molecular weight of constituent i, g/g-mol (Table B-1)

V$_m$ = standard molar volume of air, m³ (0.02445)

In areas where the pore space is not saturated (outside the 1,000 mg/kg total VOC contour), the source concentration of contaminant is based on the partitioning between contaminants adsorbed to soils in pore water and pore space air, according to Henry's law. The pore-air concentration was estimated based on the total soil concentration, as follows (Feenstra et al. 1991):

$$C_a = \frac{C_t \, \rho_d \, H}{K_d \, \rho_d + \theta_w + H \theta_a} \qquad (B-19)$$

where,

C$_a$ = source concentration of contaminant in air-filled pore space, mg/L

C$_t$ = total soil concentration, μg/g dry weight (estimated based on wet weight soil concentration; Appendix A)

ρ_d = dry bulk density of soil, g/cm³ (Table B-6)

K$_d$ = soil/water partition coefficient, cm³/g (Equation B-12)

H = Henry's Law constant, unitless (Table B-1)

θ_a = air-filled porosity of the soil beneath the cap, unitless (Table B-6)

θ_w = water-filled porosity, unitless (Table B-6)

The total chemical soil concentration, C$_t$, was determined, as discussed earlier, based on soil samples collected between depths of 3.5 feet and 7.5 feet during the 1988 subsurface soil sampling episode (dry-weight). Parameter values used in the emissions models are presented in Table B-6. Estimated long-term diffusion flux rates through overlying soil are shown in Table B-9. It should be noted that emissions from non-DNAPL containing areas were

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TABLE B-9 Estimated Flux Rates Due to Long-Term Passive Diffusion Through Overlying Soil and Soil Cover (Diffusion from DNAPL-containing Areas)			
Chemical	**Average Flux (g/sec-m^2)**		
	Lower West	**Upper West**	**Upper East**
Benzene	8.50×10^{-8}	1.90×10^{-7}	9.88×10^{-7}
Ethylbenzene	1.07×10^{-6}	1.23×10^{-6}	1.24×10^{-6}
Toluene	3.03×10^{-6}	5.97×10^{-7}	7.63×10^{-6}
Tetrachloroethene	1.81×10^{-7}	1.50×10^{-6}	3.90×10^{-7}
Trichloroethene	7.65×10^{-8}	1.83×10^{-7}	7.61×10^{-7}
1,2,3-Trichloropropane	5.22×10^{-7}	1.04×10^{-6}	8.96×10^{-7}
Xylenes	6.96×10^{-6}	6.15×10^{-6}	4.64×10^{-6}
Chemical	**Reasonable Maximum Flux (g/sec-m^2)**		
	Lower West	**Upper West**	**Upper East**
Benzene	2.80×10^{-8}	1.75×10^{-7}	1.07×10^{-6}
Ethylbenzene	1.07×10^{-6}	1.22×10^{-6}	1.27×10^{-6}
Toluene	3.03×10^{-6}	6.18×10^{-7}	7.37×10^{-6}
Tetrachloroethene	1.80×10^{-7}	1.51×10^{-6}	3.75×10^{-7}
Trichloroethene	7.11×10^{-8}	1.57×10^{-7}	8.04×10^{-7}
1,2,3-Trichloropropane	5.22×10^{-7}	1.05×10^{-6}	8.72×10^{-7}
Xylenes	6.96×10^{-6}	6.13×10^{-6}	4.73×10^{-6}

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estimated to be significantly less than emissions from DNAPL-containing soils; therefore, these types of emissions were not considered further.

3. **Passive Diffusion From and Through Backfilled Soil**

In the on-site LTTD and off-site incineration/disposal alternatives, contaminated soils in the unsaturated zone will be excavated and the area of excavation will be backfilled. Backfill material in the on-site LTTD alternative will be composed of soil treated on-site in the LTTD unit. Backfill in the off-site incineration/disposal alternative will be transported to the site from an off-site location. The backfilled LTTD-treated soil will contain residual concentrations of chemicals not removed during the LTTD treatment process; therefore, emissions of these residual volatile compounds is expected. In addition, volatile constituents in DNAPL present in the bedrock, soil, and ground water underlying the former lagoon areas is expected to diffuse upward through the backfilled soil and eventually to the atmosphere. Flux rates of chemicals of potential concern due to these two processes (emissions from LTTD-treated soil and DNAPL in the bedrock) were estimated in order to estimate potential exposure after implementation of the two alternatives involving excavation.

To estimate flux rates due to diffusion of DNAPL constituents in bedrock underlying the site, the methods described for passive diffusion through overlying soil (equations B-17 to B-20) were applied. The diffusion distance in equation (B-17) was increased, however, to represent the thickness of backfilled soil. The site-specific parameters used to model emissions due to DNAPL in the bedrock are presented in Table B-10. Estimated flux rates are presented in Table B-11.

Flux rates for chemicals of potential concern from LTTD-treated soil were estimated using an unsteady-state vapor emissions model for uncovered soils (USEPA 1986), because it was assumed that these soils represented a depleting source of emissions. Flux rates from LTTD-treated soil were estimated to be significantly less than flux rates from DNAPL in bedrock; therefore, emissions from LTTD-treated soil were not considered further in the risk assessment (i.e., chemical flux due to DNAPL in bedrock was used to estimate post-implementation exposure for the on-site LTTD and off-site incineration/disposal alternatives.

C. **Emissions From Enclosures**

Under the on-site LTTD and off-site incineration/disposal alternatives, excavated

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TABLE B-10	
Site-Specific Parameters Used to Estimate Passive Diffusion Emissions from Backfilled Soil[a]	
Parameter	**In-Situ Soil**
Air-filled Porosity, unitless	0.25
Total Soil Porosity, unitless	0.40
Bulk Soil Density (wet), g/cm³	1.6
Bulk Soil Density (dry), g/cm³	1.4
Fraction of Organic Carbon (f_{oc})	0.01

Diffusion Thickness, ft
    Lower West
    Upper West
    Upper East
	
	7
	9.5
	12

Values are based on site data and are generally consistent with EPA guidance (1992a).

a -   Backfilled soil may become recontaminated due to diffusion of chemicals from DNAPL in bedrock or have residual levels of contamination after LTTD treatment.

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TABLE B-11

Estimated Flux Rates Due to Long-Term Passive Diffusion From DNAPL in Bedrock Underlying the Site

Chemical	Average Flux (g/sec-m^2)		
	Lower West	Upper West	Upper East
Benzene	8.44×10^{-8}	1.39×10^{-7}	5.73×10^{-7}
Ethylbenzene	1.06×10^{-6}	9.00×10^{-7}	7.19×10^{-7}
Toluene	3.01×10^{-6}	4.37×10^{-7}	4.43×10^{-6}
Tetrachloroethene	1.80×10^{-7}	1.10×10^{-6}	2.26×10^{-7}
Trichloroethene	7.61×10^{-8}	1.34×10^{-7}	4.43×10^{-7}
1,2,3-Trichloropropane	5.19×10^{-7}	7.63×10^{-7}	5.19×10^{-7}
Xylenes	6.91×10^{-6}	4.50×10^{-6}	2.69×10^{-6}

Chemical	Reasonable Maximum Flux (g/sec-m^2)		
	Lower West	Upper West	Upper East
Benzene	7.75×10^{-8}	1.28×10^{-7}	6.21×10^{-7}
Ethylbenzene	1.06×10^{-6}	8.92×10^{-7}	7.39×10^{-7}
Toluene	3.01×10^{-6}	4.53×10^{-7}	4.27×10^{-6}
Tetrachloroethene	1.79×10^{-7}	1.11×10^{-6}	2.18×10^{-7}
Trichloroethene	7.07×10^{-8}	1.15×10^{-7}	4.66×10^{-7}
1,2,3-Trichloropropane	5.19×10^{-7}	7.71×10^{-7}	5.06×10^{-7}
Xylenes	6.92×10^{-6}	4.49×10^{-6}	2.74×10^{-6}

contaminated soil will be processed within an enclosure before being further treated (under the on-site LTTD alternative) or transported off-site (under the off-site incineration/disposal alternative). Within the enclosure, a number of different processes are expected to occur, including dumping the soil from the dump truck; removing and segregating boulders and cobbles from the excavated soil; and screening and crushing the soil to provide a uniform size fraction for LTTD treatment. Emissions of volatile constituents in the contaminated soil within the enclosure may be significant because of the high degree of soil handling involved in the soil processing, potentially creating high air concentrations of volatile constituents inside the enclosure. The enclosure will minimize emissions to the atmosphere through the use of air pollution control equipment associated with the air handling system of the enclosure. It is anticipated that fugitive emissions from tears, openings, and seams will occur.

Because of the complex nature of emission sources within the enclosure, estimation of emission rates from the processes within the enclosure cannot be reliably predicted. It is assumed therefore, that the mass fraction of each constituent released within the enclosure is equivalent to the fraction released from processes (active excavation and dump truck loading) outside the enclosure. Emission rates within the soil processing enclosure are summarized in Table B-12.

To estimate emissions to the atmosphere from the enclosure, it was assumed that the capture efficiency of the air pollution control devices is 90 percent (i.e., the emission rate from the enclosure is 10 percent of the emission rate within the enclosure). Furthermore, the emission rate of fugitive emissions from the enclosure was assumed to be 1 percent of the emission rate within the enclosure. Neither of these sources of emissions are expected to result in significant exposures.

The LTTD alternative involves further processing in an LTTD unit that is expected to be located outside the soil processing enclosure. Volatile constituents in the soil are removed by a countercurrent air stream in the LTTD unit, with subsequent removal from the air 2stream using activated carbon. Because the LTTD unit is fully enclosed, however, it is expected that fugitive emissions from the LTTD unit to the atmosphere will be insignificant and are not considered further.

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TABLE B-12
Estimated Emission Rates Within Soil Processing Enclosure
(Off-site Incineration/Disposal and On-Site LTTD Treatment Alternatives)

Chemical	Average Emission Rate (g/sec)		
	Lower West	Upper West	Upper East
Benzene	2.00×10^{-3}	7.86×10^{-3}	2.18×10^{-2}
Ethylbenzene	3.43×10^{-1}	4.48×10^{-1}	3.46×10^{-1}
Toluene	5.43×10^{-1}	2.49×10^{-1}	7.66×10^{-1}
Tetrachloroethene	8.02×10^{-3}	6.45×10^{-1}	1.32×10^{-1}
Trichloroethene	2.84×10^{-2}	1.10×10^{-2}	2.56×10^{-2}
1,2,3-Trichloropropane	2.88×10^{-1}	4.88×10^{-1}	3.80×10^{-1}
Xylenes	8.74×10^{-1}	1.00	7.32×10^{-1}

Chemical	Reasonable Maximum Emission Rate (g/s)		
	Lower West	Upper West	Upper East
Benzene	7.33×10^{-3}	1.62×10^{-2}	5.75×10^{-2}
Ethylbenzene	6.61×10^{-1}	6.35×10^{-1}	4.80×10^{-1}
Toluene	1.09	4.27×10^{-1}	1.06
Tetrachloroethene	3.13×10^{-1}	9.44×10^{-1}	2.83×10^{-1}
Trichloroethene	1.00×10^{-2}	2.10×10^{-2}	5.40×10^{-2}
1,2,3-Trichloropropane	5.48×10^{-1}	6.93×10^{-1}	4.94×10^{-1}
Xylenes	1.65	1.41	9.53×10^{-1}

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APPENDIX C

Simulation of Contaminant Transport

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APPENDIX C: SIMULATION OF CONTAMINANT TRANSPORT

A. Introduction

Chemicals of potential concern emitted from the site will be transported off-site by prevailing winds. The nearest residences are located to the west of the site, so receptors were conservatively assumed to be located approximately 100 meters west of the lower west lagoon, near the site boundary. To estimate the off-site concentrations of contaminants released from the site, a long-term air dispersion model was applied. The EPA-approved Industrial Source Complex model in the long-term mode (ISCLT2) was used to predict annual average concentrations of contaminants in the vicinity of the site. Air dispersion modeling was performed by estimating dispersion factors, which are defined as the predicted off-site concentrations based on a unit emission or flux rate.

The magnitude of predicted off-site concentrations is based on the configuration and location of emission sources and the local meteorological data used to predict wind flow direction and frequency. The meteorological conditions at the site were represented in the model by using an average of five years (1985 - 1989) of weather data from the Philadelphia International Airport. Air dispersion modeling was conducted for the vapor emission sources associated with the alternatives. A general description of the types and configurations of these emissions sources is provided in the following sections. Figure C-1 shows the locations of these sources. The dispersion factors that result from the air dispersion modeling described in the following sections are provided in Table C-1 for each of the following air emissions sources:

- Unsaturated zone excavation;
- Surficial soil handling (grading and basin construction);
- Enclosure emissions (fugitive and stack);
- Passive diffusion from DNAPL-containing areas; and
- Passive diffusion from DNAPL in bedrock (alternatives including excavation).

Inhalation exposure on-site may also occur to maintenance workers who routinely visit the site and trespassing children entering the site after implementation of the remedy. To

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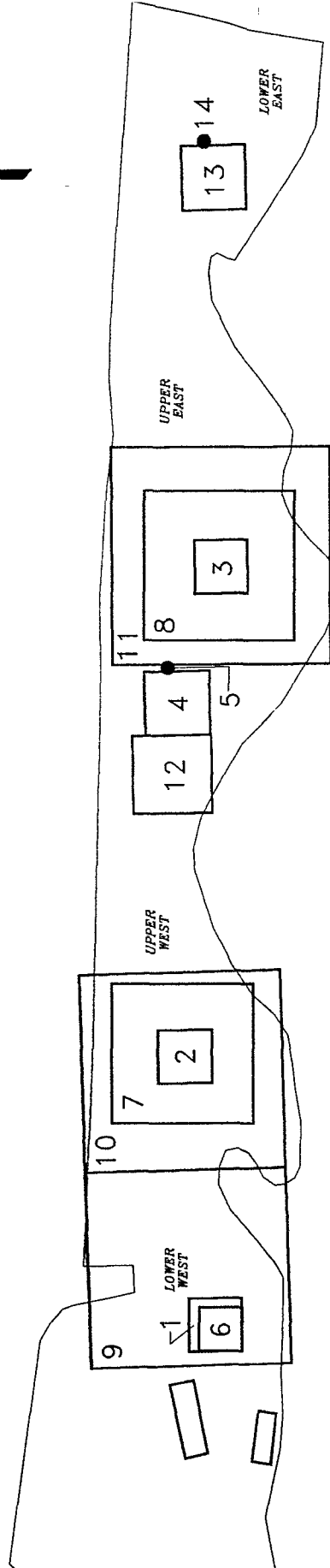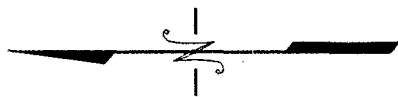
NOTES:

1,2,3 — Active excavation areas
4 — Soil processing enclosure (on—site LTTD)
5 — Enclosure stack (on—site LTTD)
6,7,8 — DNAPL—containing areas
9,10,11 — Backfill emissions areas
12 — Area representing site—wide grading
13 — Soil processing enclosure (off—site incineration)
14 — Enclosure stack (off—site incineration)

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LOCATIONS OF AIR EMISSIONS SOURCE AREAS

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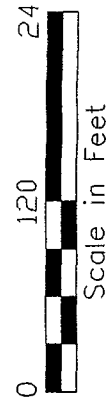
TABLE C-1
Dispersion Factors for Vapor Emission Sources and the Corresponding Remedial Alternatives

Emissions Source	Dispersion Factor μg/m³ per g/sec-m²ᵃ	Remedial Alternative				
		Soil Cover	Capping	Wet Soil Cover	On-site LTTD	Off-site Incineration/ Disposal
Excavation of Soils in the Unsaturated Zoneᵇ						
Lower West	7,769				X	X
Upper West	4,371				X	X
Upper East	1,759				X	X
Surficial Soil Handling (grading)	8,863	X	X	X		
Enclosure Sources						
Stack (centrally located)	3.3ᵃ					
Fugitive (centrally located)	10.3ᵃ				X	X
Stack (eastern area)	2.6ᵃ				X	X
Fugitive (eastern area)	5.8ᵃ					
Passive Diffusion (DNAPL Areasᶜ)						
Lower West	5,200	X	X			
Upper West	26,049	X	X			
Upper East	13,103	X	X			
Passive Diffusion (DNAPL in Bedrock)						
Lower West	76,613				X	X
Upper West	47,087				X	X
Upper East	26,024				X	X

Notes:
a - Dispersion Factor units for enclosure sources are μg/m³ per g/sec emission rate.
b - Excavation will be limited to soils with total VOC concentrations exceeding 1,000 mg/kg.
c - DNAPL-containing areas are assumed to be defined by the 1,000 mg/kg VOC contour.

estimate on-site air concentrations, a box model was used that simulates the mixing of ground-level emissions in an envelope of air on-site. A description of this model is provided in Section D of this chapter.

B. Modeling of Excavation/Soil Handling Sources

As noted in Chapter IV, excavation and soil handling may involve the highly contaminated portion of the unsaturated zone or it may involve surficial soil handling activities (e.g., grading).

1. Unsaturated Zone Excavation

For excavation of soils in the unsaturated zone, three source locations were used in the air dispersion modeling, as follows:

1) Lower West Excavation Area - Emissions from excavation activities in the lower west are represented by an area source centrally located within the area defined by ERM to contain soil with total VOC concentrations in excess of 1,000 mg/kg. The surface area of the source, 176.3 m^2, is based on two combined emission sources, 1) the active excavation pit (167 m^2) and 2) the dump truck into which excavated soil is loaded (9.3 m^2).

2) Upper West Excavation Area - As described above.

3) Upper East Excavation Area - As described above.

It should be noted that because emissions from the lower east lagoon area are insignificant in comparison with other sub-areas of the site, this sub-area was not modeled.

Depending on the alternative selected, some activities may be conducted within an enclosure (e.g., soil processing). For such cases, an enclosure source was modeled using ISCLT2. For the on-site LTTD alternative, the enclosure was assumed to be centrally located on the site. For the off-site incineration/disposal alternative, the enclosure was assumed to be located in the eastern portion of the site. It is anticipated that emissions from an enclosure will occur from two sources:

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4)   Enclosure Stack - Emissions within the enclosure will be captured using air pollution control equipment, with discharges to the atmosphere through a stack. It is assumed that 10 percent of the emissions within the enclosure will be released to the atmosphere through the stack. This source was treated as a point source in the air dispersion modeling.

5)   Fugitive Emissions from Enclosure - Fugitive emissions from the enclosure are assumed to occur through seams, punctures, openings, and leaks from between the enclosure and the ground surface. It is assumed that 1 percent of the emissions within the enclosure will be emitted to the atmosphere as fugitive emissions. This source is treated as a volume source in the air dispersion modeling.

The enclosure-related sources (4 and 5) were assumed to occur during the entire period of excavation and are not expected to be significant emission sources. The area-specific sources (1, 2, and 3) are assumed to occur for the duration of excavation in each area. Based on estimated removal volumes for each of the three sub-areas, the fraction of the entire excavation period that emissions would occur from the lower west, upper west, and upper east is 0.025, 0.305, and 0.67, respectively. These values are used in the exposure assessment to determine the off-site exposure concentrations.

2.   Surficial Soil Handling Activities

Surficial soil handling activities, such as grading, will likely be associated with several of the remedial alternatives. Air dispersion modeling of grading emissions was conducted based on the expected location and configuration of this activity. The typical surface area from which grading emissions may be expected to occur (cut areas) was estimated based on drawings of areas requiring grading (estimated as 370 m^2) prepared by ERM (personal communication, ERM 1994). To model the airborne transport of emissions from grading activities, a single, centrally located area source was used that represents the entire grading area.

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C.   **Modeling of Passive Diffusion Sources**

1.   **DNAPL-Containing Areas of Site**

Passive diffusion emissions from the DNAPL-containing areas were significantly higher than from the low concentration areas. Air dispersion modeling of diffusion emissions from the site, therefore, was limited to the DNAPL-containing areas. The location and configuration of the diffusion sources described below represents the high-concentration areas shown in Figures A-1 and A-2 (within the 1,000 mg/kg total VOC contours).

1)   Lower West Lagoon Area - Passive diffusion emissions in the lower west was represented by an area source located in the DNAPL-containing area of the lower west lagoon area. The surface area of the source, 360 m^2, is based on the area contained within the 1,000 mg/kg total VOC contour line (as shown in Figure A-1).

2)   Upper West Lagoon Area - Passive diffusion emissions in the upper west was represented by an area source located in the DNAPL-containing area of the upper west lagoon area. The surface area of the source, 830 m^2, is based on the area contained within the 1,000 mg/kg total VOC contour line (as shown in Figure A-1).

3)   East Lagoon Area - Passive diffusion emissions in the east lagoon area was represented by an area source located in the DNAPL-containing area of the east lagoon area. The surface area of the source, 1135 m^2, is based on the area contained within the 1,000 mg/kg total VOC contour line (shown in Figure A-2).

2.   **Backfilled Areas of Site**

Areas excavated under the on-site LTTD and the off-site incineration/disposal alternatives will be backfilled using treated soil or off-site soil, respectively. Treated soil which contains residual concentrations of contaminants, and backfill from off-site will be recontaminated by the upward migration of volatile DNAPL constituents trapped in the underlying bedrock, which will result in volatile emissions to the atmosphere. To model the dispersion of these emissions to off-site receptors, three

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square area sources were developed to represent each of the former lagoon areas of the site: lower west, upper west, and upper east. The surface areas of these sources were estimated to be 1,360 m² for the upper east, 112 m² for the lower west, and 1,190 m² for the upper west lagoon areas.

D. Modeling of On-site Air Concentrations

A commonly used method for estimating short-range atmospheric transport of contaminants is the box model. The box model assumes that atmospheric turbulence is the primary means of transporting contaminants emitted from the ground surface to higher elevations. Emissions from a ground-level source will tend to vertically disperse due to atmospheric turbulence as it moves downwind, forming a triangular cross section along the wind direction.

The box model used to estimate on-site concentrations, as described by Schlesinger et al. (1987), is based on the following: 1) the area of emissions defines the base of the box; 2) the height of the downwind edge of the box is defined by the trajectory of emissions from the area source, which is related to the box length, wind speed, and a roughness factor, z_o; and 3) emissions through the top of the box are considered negligible. The following equation is used to estimate the average air concentration within the box:

$$C_{Air} = \frac{ER}{H_t W \mu_z} \qquad \text{(C-1)}$$

where:

C_{Air}	=	contaminant air concentration, g/m³
ER	=	contaminant emission rate, g/sec
H_t	=	box height, m
W	=	box width, m
μ_z	=	average wind speed through the box, m/sec

The box height is determined iteratively as a function of the length of the box (for neutral atmospheric conditions) using a 100 meter box length and the following equation (Hanna et al. 1982):

where:

H_t	=	box height, m

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$$L_b = 6.25 z_o \left[\frac{H_t}{z_o} \ln\left(\frac{H_t}{z_o}\right) - 1.58\frac{H_t}{z_o} + 1.58 \right]$$ (C-2)

L_b = length of box, m

z_o = roughness height, m

The roughness height, z_o, represents various types of surface features that might affect atmospheric turbulence (e.g., plowed field, houses, urban area), and is estimated as 0.1 meters.

The final unknown in equation (C-1) is the average wind speed through the box, μ_z. Wind speed is generally measured at 10 meters at weather monitoring stations. Under neutral atmospheric conditions, wind speed decreases exponentially near the ground surface. To determine the average wind speed through the box, the following relationship was used:

$$\mu_z = 0.22 \, \mu_{10} \ln\left(\frac{H_t}{2.5 z_o}\right)$$ (C-3)

where:

μ_z = average wind speed through the box, m/sec

H_t = box height, m

z_o = roughness height, m

μ_{10} = average local wind speed at ten meters, m/sec

Based on wind speed data collected by the National Weather Service (NOAA 1985) at the Philadelphia International Airport, the average local wind speed was estimated to be 4.25 meters/sec.

Using the box model described above, average ambient air concentrations were determined on-site and used to estimate exposure to a maintenance worker and a trespasser that might visit the site after implementation of the remedy.

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APPENDIX D
Exposure Dose Summary Tables

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TABLE D-1 Estimated Average Inhalation Exposure Doses for Off-Site Resident During Implementation of the Capping Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Grading	**Passive Diffusion**
Benzene	2.32×10^{-9}	1.05×10^{-7}
Tetrachloroethene	2.79×10^{-9}	9.30×10^{-8}
Trichloroethene	2.27×10^{-9}	9.73×10^{-8}
1,2,3-Trichloropropane	1.35×10^{-8}	2.00×10^{-11}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Grading	**Passive Diffusion**
Ethylbenzene	7.05×10^{-5}	3.30×10^{-8}
Toluene	3.21×10^{-5}	1.22×10^{-4}
Tetrachloroethene	3.56×10^{-5}	2.97×10^{-5}
1,2,3-Trichloropropane	1.73×10^{-4}	6.38×10^{-9}
Xylenes	2.64×10^{-4}	2.35×10^{-5}

TABLE D-2 Estimated Reasonable Maximum Inhalation Exposure Doses for Off-Site Resident During Implementation of the Capping Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Grading	**Passive Diffusion**
Benzene	7.12×10^{-9}	3.50×10^{-7}
Tetrachloroethene	8.91×10^{-9}	1.74×10^{-7}
Trichloroethene	6.97×10^{-9}	3.08×10^{-7}
1,2,3-Trichloropropane	2.68×10^{-8}	3.00×10^{-11}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Grading	**Passive Diffusion**
Ethylbenzene	2.44×10^{-4}	6.43×10^{-8}
Toluene	9.73×10^{-5}	2.21×10^{-4}
Tetrachloroethene	1.14×10^{-4}	5.54×10^{-5}
1,2,3-Trichloropropane	3.43×10^{-4}	9.57×10^{-9}
Xylenes	5.36×10^{-4}	3.52×10^{-5}

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TABLE D-3
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident After Implementation of the Capping Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	4.53×10^{-9}	1.57×10^{-8}
Tetrachloroethene	4.60×10^{-9}	1.53×10^{-8}
Trichloroethene	2.15×10^{-9}	7.09×10^{-9}
1,2,3-Trichloropropane	2.08×10^{-7}	6.94×10^{-7}
Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	6.34×10^{-8}	6.36×10^{-8}
Toluene	2.60×10^{-7}	2.54×10^{-7}
Tetrachloroethene	3.58×10^{-8}	3.58×10^{-8}
1,2,3-Trichloropropane	1.62×10^{-6}	1.62×10^{-6}
Xylenes	5.91×10^{-7}	5.93×10^{-7}

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TABLE D-4 Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Maintenance Worker After Implementation of the Capping Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	9.14×10^{-9}	4.81×10^{-8}
Tetrachloroethene	5.55×10^{-9}	2.76×10^{-8}
Trichloroethene	$4.21\text{'}\times 10^{-9}$	2.14×10^{-8}
1,2,3-Trichloropropane	3.35×10^{-7}	1.66×10^{-6}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	2.04×10^{-7}	2.05×10^{-7}
Toluene	1.15×10^{-6}	1.13×10^{-6}
Tetrachloroethene	7.77×10^{-8}	7.73×10^{-8}
1,2,3-Trichloropropane	4.69×10^{-6}	4.66×10^{-6}
Xylenes	1.96×10^{-6}	1.97×10^{-6}

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TABLE D-5 Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Trespasser After Implementation of the Capping Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	1.78×10^{-9}	6.00×10^{-9}
Tetrachloroethene	1.08×10^{-9}	3.45×10^{-9}
Trichloroethene	8.22×10^{-10}	2.67×10^{-9}
1,2,3-Trichloropropane	6.54×10^{-8}	2.08×10^{-7}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	3.31×10^{-8}	1.07×10^{-7}
Toluene	1.87×10^{-7}	5.86×10^{-7}
Tetrachloroethene	1.26×10^{-8}	4.02×10^{-8}
1,2,3-Trichloropropane	7.63×10^{-7}	2.42×10^{-6}
Xylenes	3.18×10^{-7}	1.02×10^{-6}

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TABLE D-6
Estimated Average Inhalation Exposure Doses for Off-Site Resident
During Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Grading	Passive Diffusion
Benzene	2.32×10^{-9}	9.17×10^{-8}
Tetrachloroethene	2.79×10^{-9}	8.13×10^{-8}
Trichloroethene	2.27×10^{-9}	8.51×10^{-8}
1,2,3-Trichloropropane	1.35×10^{-8}	1.75×10^{-11}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Grading	Passive Diffusion
Ethylbenzene	7.05×10^{-5}	3.30×10^{-8}
Toluene	3.21×10^{-5}	1.22×10^{-4}
Tetrachloroethene	3.56×10^{-5}	2.97×10^{-5}
1,2,3-Trichloropropane	1.73×10^{-4}	6.38×10^{-9}
Xylenes	2.64×10^{-4}	2.35×10^{-5}

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	TABLE D-7 **Estimated Reasonable Maximum (RME) Exposure Doses for Off-Site Resident** **During Implementation of the Soil Cover Alternative**		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**		
	Grading	**Passive Diffusion**	
Benzene	7.12×10^{-9}	3.07×10^{-7}	
Tetrachloroethene	8.91×10^{-9}	1.52×10^{-7}	
Trichloroethene	6.97×10^{-9}	2.70×10^{-7}	
1,2,3-Trichloropropane	2.68×10^{-8}	2.62×10^{-11}	
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**		
	Grading	**Passive Diffusion**	
Ethylbenzene	2.44×10^{-4}	6.43×10^{-8}	
Toluene	9.73×10^{-5}	2.21×10^{-4}	
Tetrachloroethene	1.14×10^{-4}	5.54×10^{-5}	
1,2,3-Trichloropropane	3.43×10^{-4}	9.57×10^{-9}	
Xylenes	5.36×10^{-4}	3.52×10^{-5}	

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TABLE D-8

Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	6.46×10^{-7}	2.23×10^{-6}
Tetrachloroethene	1.59×10^{-6}	5.31×10^{-6}
Trichloroethene	5.34×10^{-7}	1.76×10^{-6}
1,2,3-Trichloropropane	1.47×10^{-6}	4.88×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	1.47×10^{-5}	1.48×10^{-5}
Toluene	3.60×10^{-5}	3.52×10^{-5}
Tetrachloroethene	1.24×10^{-5}	1.24×10^{-5}
1,2,3-Trichloropropane	1.14×10^{-5}	1.14×10^{-5}
Xylenes	7.05×10^{-5}	7.06×10^{-5}

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TABLE D-9
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Maintenance Worker After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.30×10^{-6}	6.85×10^{-6}
Tetrachloroethene	1.92×10^{-6}	9.56×10^{-6}
Trichloroethene	1.05×10^{-6}	5.31×10^{-6}
1,2,3-Trichloropropane	2.36×10^{-6}	1.17×10^{-5}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	4.73×10^{-5}	4.77×10^{-5}
Toluene	1.60×10^{-4}	1.56×10^{-4}
Tetrachloroethene	2.69×10^{-5}	2.68×10^{-5}
1,2,3-Trichloropropane	3.30×10^{-5}	3.28×10^{-5}
Xylenes	2.33×10^{-4}	2.35×10^{-4}

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TABLE D-10
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Trespasser After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	2.54×10^{-7}	8.55×10^{-7}
Tetrachloroethene	3.75×10^{-7}	1.19×10^{-6}
Trichloroethene	2.04×10^{-7}	6.64×10^{-7}
1,2,3-Trichloropropane	4.60×10^{-7}	1.46×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	7.70×10^{-6}	2.48×10^{-5}
Toluene	2.59×10^{-5}	8.11×10^{-5}
Tetrachloroethene	4.37×10^{-6}	1.39×10^{-5}
1,2,3-Trichloropropane	5.36×10^{-6}	1.70×10^{-5}
Xylenes	3.80×10^{-5}	1.22×10^{-4}

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TABLE D-11
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Maintenance Worker After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.92×10^{-10}	1.62×10^{-9}
Tetrachloroethene	5.15×10^{-10}	5.90×10^{-9}
Trichloroethene	1.92×10^{-10}	1.62×10^{-9}
1,2,3-Trichloropropane	2.60×10^{-9}	2.60×10^{-8}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	5.14×10^{-9}	9.42×10^{-9}
Toluene	3.91×10^{-9}	6.85×10^{-9}
Tetrachloroethene	7.22×10^{-9}	1.65×10^{-8}
1,2,3-Trichloropropane	3.64×10^{-8}	7.28×10^{-8}
Xylenes	5.20×10^{-8}	9.19×10^{-8}

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TABLE D-12
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Maintenance Worker After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.92×10^{-10}	1.62×10^{-9}
Tetrachloroethene	5.15×10^{-10}	5.90×10^{-9}
Trichloroethene	1.92×10^{-10}	1.62×10^{-9}
1,2,3-Trichloropropane	2.60×10^{-9}	2.60×10^{-8}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	5.14×10^{-9}	9.42×10^{-9}
Toluene	3.91×10^{-9}	6.85×10^{-9}
Tetrachloroethene	7.22×10^{-9}	1.65×10^{-8}
1,2,3-Trichloropropane	3.64×10^{-8}	7.28×10^{-8}
Xylenes	5.20×10^{-8}	9.19×10^{-8}

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TABLE D-13 Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Trespasser After Implementation of the Soil Cover Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	6.25×10^{-11}	2.10×10^{-10}
Tetrachloroethene	1.68×10^{-10}	7.67×10^{-10}
Trichloroethene	6.25×10^{-11}	2.10×10^{-10}
1,2,3-Trichloropropane	8.47×10^{-10}	3.38×10^{-9}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	1.38×10^{-9}	5.10×10^{-9}
Toluene	1.06×10^{-9}	3.71×10^{-9}
Tetrachloroethene	1.96×10^{-9}	8.95×10^{-9}
1,2,3-Trichloropropane	9.88×10^{-9}	3.94×10^{-8}
Xylenes	1.41×10^{-8}	4.98×10^{-8}

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TABLE D-14
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Trespasser After Implementation of the Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.66×10^{-11}	1.40×10^{-10}
Tetrachloroethene	4.46×10^{-11}	5.10×10^{-10}
Trichloroethene	1.66×10^{-11}	1.40×10^{-10}
1,2,3-Trichloropropane	2.25×10^{-10}	2.25×10^{-9}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	3.70×10^{-10}	3.39×10^{-9}
Toluene	2.82×10^{-10}	2.47×10^{-9}
Tetrachloroethene	5.20×10^{-10}	5.95×10^{-9}
1,2,3-Trichloropropane	2.63×10^{-9}	2.62×10^{-8}
Xylenes	3.75×10^{-9}	3.31×10^{-8}

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TABLE D-15
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident During Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	9.32×10^{-7}	2.98×10^{-6}
Tetrachloroethene	3.23×10^{-6}	6.68×10^{-6}
Trichloroethene	1.15×10^{-6}	3.20×10^{-6}
1,2,3-Trichloropropane	2.54×10^{-6}	5.27×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	6.44×10^{-4}	1.34×10^{-3}
Toluene	9.67×10^{-4}	1.97×10^{-3}
Tetrachloroethene	8.33×10^{-4}	1.73×10^{-3}
1,2,3-Trichloropropane	6.55×10^{-4}	1.36×10^{-3}
Xylenes	1.34×10^{-3}	2.80×10^{-3}

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TABLE D-16 Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident After Implementation of the Off-Site Incineration/Disposal Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	3.73×10^{-7}	1.27×10^{-6}
Tetrachloroethene	9.44×10^{-7}	3.15×10^{-6}
Trichloroethene	3.12×10^{-7}	1.03×10^{-6}
1,2,3-Trichloropropane	1.04×10^{-6}	3.45×10^{-6}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	1.19×10^{-5}	1.19×10^{-5}
Toluene	3.00×10^{-5}	2.96×10^{-5}
Tetrachloroethene	7.34×10^{-6}	7.34×10^{-6}
1,2,3-Trichloropropane	8.05×10^{-6}	8.05×10^{-6}
Xylenes	6.43×10^{-5}	6.44×10^{-5}

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TABLE D-17
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Maintenance Worker After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	8.12×10^{-7}	4.24×10^{-6}
Tetrachloroethene	1.39×10^{-6}	6.91×10^{-6}
Trichloroethene	6.60×10^{-7}	3.32×10^{-6}
1,2,3-Trichloropropane	1.70×10^{-6}	8.47×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	3.53×10^{-5}	3.55×10^{-5}
Toluene	1.09×10^{-4}	1.07×10^{-4}
Tetrachloroethene	1.94×10^{-5}	1.93×10^{-5}
1,2,3-Trichloropropane	2.38×10^{-5}	2.37×10^{-5}
Xylenes	1.83×10^{-4}	1.84×10^{-4}

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TABLE D-18
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Trespasser After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.58×10^{-7}	5.29×10^{-7}
Tetrachloroethene	2.70×10^{-7}	8.63×10^{-7}
Trichloroethene	1.29×10^{-7}	4.15×10^{-7}
1,2,3-Trichloropropane	3.32×10^{-7}	1.06×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	5.75×10^{-6}	1.85×10^{-5}
Toluene	1.78×10^{-5}	5.58×10^{-5}
Tetrachloroethene	3.16×10^{-6}	1.01×10^{-5}
1,2,3-Trichloropropane	3.87×10^{-6}	1.23×10^{-5}
Xylenes	2.98×10^{-5}	9.56×10^{-5}

TABLE D-19
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Maintenance Worker After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	4.37×10^{-12}	2.62×10^{-11}
Tetrachloroethene	4.37×10^{-12}	2.62×10^{-11}
Trichloroethene	4.37×10^{-12}	2.62×10^{-11}
1,2,3-Trichloropropane	3.84×10^{-11}	4.72×10^{-10}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	6.12×10^{-11}	7.34×10^{-11}
Toluene	6.12×10^{-11}	7.34×10^{-11}
Tetrachloroethene	6.12×10^{-11}	7.34×10^{-11}
1,2,3-Trichloropropane	5.38×10^{-10}	1.32×10^{-9}
Xylenes	6.12×10^{-11}	7.34×10^{-11}

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TABLE D-20
Estimated Average and Reasonable Maximum (RME) Dermal Contact Exposure with Soil Doses for Maintenance Worker After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	4.37×10^{-12}	2.62×10^{-11}
Tetrachloroethene	4.37×10^{-12}	2.62×10^{-11}
Trichloroethene	4.37×10^{-12}	2.62×10^{-11}
1,2,3-Trichloropropane	3.84×10^{-11}	4.72×10^{-10}
Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	6.12×10^{-11}	7.34×10^{-11}
Toluene	6.12×10^{-11}	7.34×10^{-11}
Tetrachloroethene	6.12×10^{-11}	7.34×10^{-11}
1,2,3-Trichloropropane	5.38×10^{-10}	1.32×10^{-9}
Xylenes	6.12×10^{-11}	7.34×10^{-11}

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TABLE D-21
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Trespasser After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.42×10^{-12}	3.41×10^{-12}
Tetrachloroethene	1.42×10^{-12}	3.41×10^{-12}
Trichloroethene	1.42×10^{-12}	3.41×10^{-12}
1,2,3-Trichloropropane	1.25×10^{-11}	6.14×10^{-11}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	1.66×10^{-11}	3.98×10^{-11}
Toluene	1.66×10^{-11}	3.98×10^{-11}
Tetrachloroethene	1.66×10^{-11}	3.98×10^{-11}
1,2,3-Trichloropropane	1.46×10^{-10}	7.16×10^{-10}
Xylenes	1.66×10^{-11}	3.98×10^{-11}

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TABLE D-22
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Trespasser After Implementation of the Off-Site Incineration/Disposal Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	3.78×10^{-13}	2.27×10^{-12}
Tetrachloroethene	3.78×10^{-13}	2.27×10^{-12}
Trichloroethene	3.78×10^{-13}	2.27×10^{-12}
1,2,3-Trichloropropane	3.32×10^{-12}	4.08×10^{-11}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	4.41×10^{-12}	2.64×10^{-11}
Toluene	4.41×10^{-12}	2.64×10^{-11}
Tetrachloroethene	4.41×10^{-12}	2.64×10^{-11}
1,2,3-Trichloropropane	3.88×10^{-11}	4.76×10^{-10}
Xylenes	4.41×10^{-12}	2.64×10^{-11}

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TABLE D-23 Estimated Average Inhalation Exposure Doses for Off-Site Resident During Implementation of Wet Soil Cover Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Grading	**Passive Diffusion**
Benzene	2.32×10^{-9}	1.14×10^{-7}
Tetrachloroethene	2.79×10^{-9}	3.74×10^{-7}
Trichloroethene	2.27×10^{-9}	1.03×10^{-7}
1,2,3-Trichloropropane	1.35×10^{-8}	2.41×10^{-11}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Grading	**Passive Diffusion**
Ethylbenzene	7.05×10^{-5}	3.38×10^{-8}
Toluene	3.21×10^{-5}	3.96×10^{-5}
Tetrachloroethene	3.56×10^{-5}	1.06×10^{-4}
1,2,3-Trichloropropane	1.73×10^{-4}	6.84×10^{-9}
Xylenes	2.64×10^{-4}	2.51×10^{-5}

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TABLE D-24
Estimated Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident During Implementation of Wet Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Grading	Passive Diffusion
Benzene	7.12×10^{-9}	4.18×10^{-7}
Tetrachloroethene	8.91×10^{-9}	8.78×10^{-7}
Trichloroethene	6.97×10^{-9}	3.68×10^{-7}
1,2,3-Trichloropropane	2.68×10^{-8}	3.61×10^{-11}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Grading	Passive Diffusion
Ethylbenzene	2.44×10^{-4}	7.16×10^{-8}
Toluene	9.73×10^{-5}	6.54×10^{-5}
Tetrachloroethene	1.14×10^{-4}	2.49×10^{-4}
1,2,3-Trichloropropane	3.43×10^{-4}	1.03×10^{-8}
Xylenes	5.36×10^{-4}	3.77×10^{-5}

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TABLE D-25
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Maintenance Worker After Implementation of the Wet Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.92×10^{-10}	1.62×10^{-9}
Tetrachloroethene	5.15×10^{-10}	5.90×10^{-9}
Trichloroethene	1.92×10^{-10}	1.62×10^{-9}
1,2,3-Trichloropropane	2.60×10^{-9}	2.60×10^{-8}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	5.14×10^{-9}	9.42×10^{-9}
Toluene	3.91×10^{-9}	6.85×10^{-9}
Tetrachloroethene	7.22×10^{-9}	1.65×10^{-8}
1,2,3-Trichloropropane	3.64×10^{-8}	7.28×10^{-8}
Xylenes	5.20×10^{-8}	9.19×10^{-8}

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TABLE D-26 Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Maintenance Worker After Implementation of the Wet Soil Cover Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	1.92×10^{-10}	1.62×10^{-9}
Tetrachloroethene	5.15×10^{-10}	5.90×10^{-9}
Trichloroethene	1.92×10^{-10}	1.62×10^{-9}
1,2,3-Trichloropropane	2.60×10^{-9}	2.60×10^{-8}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	5.14×10^{-9}	9.42×10^{-9}
Toluene	3.91×10^{-9}	6.85×10^{-9}
Tetrachloroethene	7.22×10^{-9}	1.65×10^{-8}
1,2,3-Trichloropropane	3.64×10^{-8}	7.28×10^{-8}
Xylenes	5.20×10^{-8}	9.19×10^{-8}

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TABLE D-27
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Trespasser After Implementation of the Wet Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	6.25×10^{-11}	2.10×10^{-10}
Tetrachloroethene	1.68×10^{-10}	7.67×10^{-10}
Trichloroethene	6.25×10^{-11}	2.10×10^{-10}
1,2,3-Trichloropropane	8.47×10^{-10}	3.38×10^{-9}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	1.38×10^{-9}	5.10×10^{-9}
Toluene	1.06×10^{-9}	3.71×10^{-9}
Tetrachloroethene	1.96×10^{-9}	8.95×10^{-9}
1,2,3-Trichloropropane	9.88×10^{-9}	3.94×10^{-8}
Xylenes	1.41×10^{-8}	4.98×10^{-8}

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TABLE D-28
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Trespasser After Implementation of the Wet Soil Cover Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.66×10^{-11}	1.40×10^{-10}
Tetrachloroethene	4.46×10^{-11}	5.10×10^{-10}
Trichloroethene	1.66×10^{-11}	1.40×10^{-10}
1,2,3-Trichloropropane	2.25×10^{-10}	2.25×10^{-9}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	3.70×10^{-10}	3.39×10^{-9}
Toluene	2.82×10^{-10}	2.47×10^{-9}
Tetrachloroethene	5.20×10^{-10}	5.95×10^{-9}
1,2,3-Trichloropropane	2.63×10^{-9}	2.62×10^{-8}
Xylenes	3.75×10^{-9}	3.31×10^{-8}

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TABLE D-29
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident During Implementation of the On-Site LTTD Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	9.33×10^{-7}	2.98×10^{-6}
Tetrachloroethene	3.24×10^{-6}	6.72×10^{-6}
Trichloroethene	1.15×10^{-6}	3.21×10^{-6}
1,2,3-Trichloropropane	2.56×10^{-6}	5.30×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	6.48×10^{-4}	1.35×10^{-3}
Toluene	9.74×10^{-4}	1.99×10^{-3}
Tetrachloroethene	8.37×10^{-4}	1.73×10^{-3}
1,2,3-Trichloropropane	6.60×10^{-4}	1.37×10^{-3}
Xylenes	1.35×10^{-3}	2.82×10^{-3}

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TABLE D-30		
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Off-Site Resident After Implementation of the On-Site LTTD Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	3.73×10^{-7}	1.27×10^{-6}
Tetrachloroethene	9.44×10^{-7}	3.15×10^{-6}
Trichloroethene	3.12×10^{-7}	1.03×10^{-6}
1,2,3-Trichloropropane	1.04×10^{-6}	3.45×10^{-6}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	1.19×10^{-5}	1.19×10^{-5}
Toluene	3.00×10^{-5}	2.96×10^{-5}
Tetrachloroethene	7.34×10^{-6}	7.34×10^{-6}
1,2,3-Trichloropropane	8.05×10^{-6}	8.05×10^{-6}
Xylenes	6.43×10^{-5}	6.44×10^{-5}

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TABLE D-31		
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Maintenance Worker After Implementation of the On-Site LTTD Alternative		
Chemical	**Exposure Dose (mg/kg-day) for Carcinogens**	
	Average	**RME**
Benzene	8.12×10^{-7}	4.24×10^{-6}
Tetrachloroethene	1.39×10^{-6}	6.91×10^{-6}
Trichloroethene	6.60×10^{-7}	3.32×10^{-6}
1,2,3-Trichloropropane	1.70×10^{-6}	8.47×10^{-6}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	**RME**
Ethylbenzene	3.53×10^{-5}	3.55×10^{-5}
Toluene	1.09×10^{-4}	1.07×10^{-4}
Tetrachloroethene	1.94×10^{-5}	1.93×10^{-5}
1,2,3-Trichloropropane	2.38×10^{-5}	2.37×10^{-5}
Xylenes	1.83×10^{-4}	1.84×10^{-4}

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TABLE D-32
Estimated Average and Reasonable Maximum (RME) Inhalation Exposure Doses for Trespasser
After Implementation of the On-Site LTTD Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.58×10^{-7}	5.29×10^{-7}
Tetrachloroethene	2.70×10^{-7}	8.63×10^{-7}
Trichloroethene	1.29×10^{-7}	4.15×10^{-7}
1,2,3-Trichloropropane	3.32×10^{-7}	1.06×10^{-6}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	5.75×10^{-6}	1.85×10^{-5}
Toluene	1.78×10^{-5}	5.58×10^{-5}
Tetrachloroethene	3.16×10^{-6}	1.01×10^{-5}
1,2,3-Trichloropropane	3.87×10^{-6}	1.23×10^{-5}
Xylenes	2.98×10^{-5}	9.56×10^{-5}

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TABLE D-33		
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Maintenance Worker After Implementation of the On-Site LTTD Alternative		

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	2.22×10^{-11}	2.88×10^{-10}
Tetrachloroethene	5.10×10^{-9}	6.57×10^{-8}
Trichloroethene	4.43×10^{-11}	2.82×10^{-10}
1,2,3-Trichloropropane	5.37×10^{-8}	6.31×10^{-7}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	2.60×10^{-7}	7.00×10^{-7}
Toluene	1.70×10^{-7}	5.00×10^{-7}
Tetrachloroethene	7.10×10^{-8}	1.80×10^{-7}
1,2,3-Trichloropropane	7.50×10^{-7}	1.80×10^{-6}
Xylenes	2.00×10^{-6}	5.20×10^{-6}

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TABLE D-34
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Maintenance Worker After Implementation of the On-Site LTTD Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	2.22×10^{-11}	2.88×10^{-10}
Tetrachloroethene	5.10×10^{-9}	6.57×10^{-8}
Trichloroethene	4.43×10^{-11}	2.82×10^{-10}
1,2,3-Trichloropropane	5.37×10^{-8}	6.31×10^{-7}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	2.60×10^{-7}	7.00×10^{-7}
Toluene	1.70×10^{-7}	5.00×10^{-7}
Tetrachloroethene	7.10×10^{-8}	1.80×10^{-7}
1,2,3-Trichloropropane	7.50×10^{-7}	1.80×10^{-6}
Xylenes	2.00×10^{-6}	5.20×10^{-6}

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TABLE D-35
Estimated Average and Reasonable Maximum (RME) Soil Ingestion Exposure Doses for Trespasser After Implementation of the On-Site LTTD Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	7.23×10^{-12}	3.75×10^{-11}
Tetrachloroethene	1.66×10^{-9}	8.54×10^{-9}
Trichloroethene	1.44×10^{-11}	3.67×10^{-11}
1,2,3-Trichloropropane	1.75×10^{-8}	8.21×10^{-8}
Chemical	**Exposure Dose (mg/kg-day) for Noncarcinogens**	
	Average	RME
Ethylbenzene	7.10×10^{-8}	3.80×10^{-7}
Toluene	4.70×10^{-8}	2.70×10^{-7}
Tetrachloroethene	1.90×10^{-8}	1.00×10^{-7}
1,2,3-Trichloropropane	2.00×10^{-7}	9.60×10^{-7}
Xylenes	5.30×10^{-7}	2.80×10^{-6}

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TABLE D-36
Estimated Average and Reasonable Maximum (RME) Dermal Contact with Soil Exposure Doses for Trespasser After Implementation of the On-Site LTTD Alternative

Chemical	Exposure Dose (mg/kg-day) for Carcinogens	
	Average	RME
Benzene	1.92×10^{-12}	2.49×10^{-11}
Tetrachloroethene	4.41×10^{-10}	5.68×10^{-9}
Trichloroethene	3.83×10^{-12}	2.44×10^{-11}
1,2,3-Trichloropropane	4.64×10^{-9}	5.46×10^{-8}

Chemical	Exposure Dose (mg/kg-day) for Noncarcinogens	
	Average	RME
Ethylbenzene	1.90×10^{-8}	2.50×10^{-7}
Toluene	1.20×10^{-8}	1.80×10^{-7}
Tetrachloroethene	5.10×10^{-9}	6.60×10^{-8}
1,2,3-Trichloropropane	5.40×10^{-8}	6.40×10^{-7}
Xylenes	1.40×10^{-7}	1.90×10^{-6}

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Appendix G
Detailed Cost Estimates

DETAILED COST ESTIMATES
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1.0   GENERAL BASIS AND ASSUMPTIONS:

The alternatives included in this cost estimate are:

       Alternative 1 - Soil Cover (TABLE G-1)

       Alternative 2 - Capping (TABLE G-2)

       Alternative 3 - Wet Soil Cover (TABLE G-3)

       Alternative 4 - On-site LTTD (TABLE G-4)

       Alternative 5 - Off-site Incineration/Disposal (TABLE G-5)

The quantities of work are estimated from site maps, various site-related data and previous reports. Unit costs for routine work items are primarily from recent bid prices and Means cost data adjusted to the site conditions. Unit costs from specific sources and vendor's quotes are indicated. All other costs are based on cost engineer's professional judgment and estimation methods are shown when applicable. The unit costs developed in this manner are presented in the cost tables as low and high end unit costs to represent a realistic project cost range.

Direct construction costs include contractor's profit and provisions for health/safety related costs and delays.

Contractor's indirect costs are assumed to be 10% of direct construction cost to include insurance, office overhead, and technical support.

Uncertainties (scope of work, site conditions, regulatory, etc.) inherent to the project are reflected by a contingency factor of 20%.

The operation and maintenance (O/M) costs are based on 30 years of operation at a discount rate of 5%, unless other specific conditions apply.

For five-year reviews, the total present worth of the six reviews is $69,550 based on $25,000 per review and the present worth (PW) factor of 2.782 for six reviews until year 30.

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1.1   *Alternative 1: Soil Cover (TABLE G-1)*

Cover area - 83,000 ft^2 from FFS Figure 3-1.

Soil cover consists of grass cover, 6-in topsoil and 18-in general fill on the regraded surface.

Construction schedule - A total of 4 months based on 2 months cover construction and 2 months for mob/demob, site preparation, fence and sediment ponds. Schedule estimates are based on 6-day work week.

Site management cost includes site trailers, offices, support personnel, site managers and miscellaneous site expenses.

O/M costs include air monitoring, inspection, reporting, cover/fence maintenance, etc. but do not include ground water sampling and analysis that may be a part of the long-term ground water program.

1.2   *Alternative 2: Capping (TABLE G-2)*

The cap area is 83,000 ft^2 (from Figure 3-1).

Capping consists of grass cover, 6-in topsoil, 18-in general fill, and 24-in clay on the regraded surface.

An active venting layer is included in the capping alternative cost estimate for possible future use in the event that VOC emissions result in unacceptable risk.

Venting pipe - Parallel pipes about 50 feet apart along the length of the lagoon as shown on Figure 3-2, the total length is 2,660 feet including the manifold and lead to the vapor treatment building.

Vapor treatment system - Assume venting is required from Year 11 to Year 30. Install a low flow vapor treatment unit (Carbtrol SVX R-3, 200 cfm, two 2,000 lbs carbon canisters) at the end of Year 10. The annual O/M costs will include carbon replacement and disposal, system maintenance, solvent disposal, and one quarter-time maintenance mechanic.

Work Item	Year	Cost ($)	PW factor	PW Cost
Installation	10	30,000	0.6139	18,500
Mechanic	11-30	15,000	7.65	114,750

| O/M others | 11-30 | 25,000 | 7.65 | 191,250 |
| | | | Total | $324,500 |

Construction schedule - A total of 5 months based on 3 months cap construction and 2 months for other work. Schedule estimates are based on 6-day work week.

1.3 *Alternative 3: Wet Soil Barrier (TABLE G-3)*

Cover area - 83,000 ft^2 from Figure 3-1.

The cover consists of grass cover, 6-in topsoil, 6-in general fill, 12-in sand layer as an infiltration blanket and 18-in reworked, compacted in-situ soil. An irrigation system is installed to introduce water into the lagoon soil.

Assume five more ground water monitoring wells to monitor water levels for infiltration rate control.

Construction schedule - A total of 5 months based on 3 months for cover/blanket construction, 2 months for for mob/demob, site preparation, fence and sediment ponds. Schedule estimates are based on 6-day work week.

O/M costs include infiltration system operation and all other components required for soil cover.

1.4 *Alternative 4: On-Site LTTD (TABLE G-4)*

Treatment unit - indirect heating and the treatment capacity of 8 tons per hour.

The total soil volume requiring excavation is 13,070 cubic yards (19,600 wet tons) based on unsaturated soil with VOCs in excess of 1,000 mg/kg and some surrounding soils. The site will be closed with a soil cover.

Excavation and soil preparation unit cost, 200 tons/day, 8-hr work day.

Excavator and operator	$1,200
One dump truck with driver	$800
Grizzly/hammermill plant and operator	$1,600
One superintendent & one laborer	$880
One maintenance mechanic	$400

Health and safety supplies and services	$1,200
Two health/safety specialist with instruments	$1,800
Total	$7,880

Unit cost = $7,880/200 tons = $39.4/ton, use $40/ton

Enclosure structure for soil preprocessing (60' x 80' Sprung, quote from Sprung)

Structure purchase	$120,000
Freight	$6,000
Installation crew 8 x 6 days x $400	$19,200
Crane for 8 days + mob/demob	$20,000
Removal and salvage/disposal	$10,000
Support equipment and supervision	$10,000
Total	$185,200

Feeding unit cost - Use a front end loader inside the enclosure, 24 hr/day. For the loader daily cost of $3,120 (24-hr/day), the unit cost of feeding is $3,120/200 = $15.6/ton, use $16/ton.

Vapor treatment capital cost for ventilation of the enclosure - use existing SVE treatment system and blowers.

Initial carbon changeout	$20,000
Piping modifications and instrument	$20,000
Duct work from enclosure to building	$20,000
Total	$60,000

Vapor treatment O/M per month during soil processing

O/M by one day-shift operator	$1,000
Fuel, power, and supplies	$700
Solvent disposal (included in LTTD cost)	
Total	$1,700/mo.

LTTD processing unit cost - ETG's quote dated 12/9/93 was $114/ton for 35,500 tons. Use $130/ton for 19,600 tons.

Backfill unit cost for soil based on 200 tons/day

Loader and operator (5-hr work)	$600
Dump truck and driver (5-hr work)	$600
Compactor and operator (5-hr work)	$400
Health and safety supplies and services	$300
Total	$1,900

Unit cost   1,900/200 = $9.5/ton,   use $10/ton

Use the same unit cost for boulder/cobble backfill.

Boulder and cobble segregared by grizzly screening will be backfilled at the bottom of the excavation pit. The estimated quantity of boulder and cobble is about 6% of the soil quantity or 1,200 tons.

Test run - assume two test runs, each to treat 500 tons.

Processing (from ETG)	500 tons x $130/ton = $65,000
Standby (from ETG)	$25,000/wk x 5 wks = $125,000
Analytical	50 samples x $600 = $30,000
Engineering support	$50,000
Total	$270,000

VOC liquid disposal:

Disposal cost/ton at Rollins (from Ciba) $0.21/lb x 2000 = $420/ton

Unit cost for hauling, handling and carbon regeneration = $800/ton

Total remaining quantity of VOCs in the unsaturated soil is estimated to be about 75 tons . Excavation of 19,600 tons is expected to remove about 99% of the VOCs in the unsaturated soill. Thus, the total quantity of the VOCs requiring disposal is 74.25 tons.

Schedule estimate for 19,600 tons and 8 TPH based on 7-day, 24-hr operation for LTTD, 7-day, 8-hr operation for soil excavation and processing and 6-day work week for other work.

Nominal processing time - 19,600/(8x24) = 102 days

80% operating time, 80% capacity - 102/(0.8 x 0.8) = 160 days

Mob/demob, set up, test run, approval delays - 80 days

LTTD operation 8 mo. + capping/closure 4 mo = 12 months

The total soil volume requiring excavation is 13,070 cubic yards (19,600 wet tons) based on unsaturated soil with VOCs in excess of 1,000 mg/kg and some surrounding soils. The site will be closed with a soil cover.

Assume transportation by rail at 200 tons/day to the Clive facility, Utah owned by USPCI.

Boulder/cobble handling - Screen through a 6-in grizzly in an enclosure and backfill at the bottom of the excavation pit. The estimated quantity of boulder/cobble is about 6% of the total soil quantity or 1,200 ton.

Railroad loading track - #10 turnout switch $90,000, siding track $60,000 (500ft x $120/ft) (quote from W. E. Yoder, Inc. in the 4/30/93 letter to ERM and subsequent clarification summarized in ERM's letter to Ciba dated 5/17/93)

Loading dock construction - 200 ft long, 30 ft wide

Clearing, grading and foundation excavation	$10,000
Structural concrete wall, reinforced, 200' long, 5' high wall, 3' wide footing, 1' thick 1,600 cf x $15 = $24,000	
Surface paving, 9" stone base and 4" asphalt concrete	
200' x 30'/9 = 670 sy 670 sy x $20/sy = $13,400	
Disposal of excavated material 300 tons x $100 = $30,000	
Total	$73,400

Excavation and boulder screening (in an enclosure) unit cost, 200 tons/day, 8-hr work day.

Excavator and operator	$1,200/day
One dump truck with driver	$800/day
Grizzly and operator	$1,000/day
One superintendent and one laborer	$880/day
One maintenance mechanic	$400/day
Health and safety supplies and services	$1,200/day
One health/safety specialist with instruments	$900/day
Total	$7,880/day

Unit cost = $7,880/200 tons = $39.4/ton,   use $40/ton

Backfilling unit costs - $13/ton for soil to import and place, $10/ton for boulder/cobble

Vapor treatment for enclosure (from LTTD cost estimate) - $60,000 for capital cost, $1,700/mo. for monthly O/M.

Loading unit cost for 200 tons/day loading operation

Loader and operator for filling roll-off boxes	$1,200/day
One trailer truck with driver	$1,200/day
One crane with operator ($200 x 6 hr)	$1,200/day
One superintendent	0/day
One decontamination laborer	$240/day
Total	$4,400/day

Unit cost = $4,400/200 = $22/ton

Transportation unit cost - Conrail's quote dated 12/3/93, $7,100/car or $71/ton. Use $80/ton to consider demurrage and incidental costs.

Off-site incineration unit cost (quote from USPCI summarized in ERM's memo dated 1/3/94) with all regulatory compliance, analytical, disposal and container use $700 to $850/ton

Loading dock demolition and disposal

Demolition	1600 cf x $12/cf = $19,200
Load/haul/disposal	1600 cf x 150/2,000 = 120 tons
	120 tons x $100 = $12,000
Total	$31,200

Schedule (19,600 tons, 200 TPD), assume 6-day work week.

Excavation/shipping time = 19,600/200 =	93 days
75% operating time = 122/0.75 =	124 days
Other activities (loading dock, closure, etc.) =	5 months
Total schedule =	9 months

TABLE G-1 PROBABLE COST FOR ALTERNATIVE 1, SOIL COVER

Date: 11/4/94

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($)		TOTAL COST ($)	
			LOW	HIGH	LOW	HIGH
1.0 MOBILIZATION/DEMOBILIZATION	L.S.	1	60,000	80,000	60,000	80,000
2.0 DECOMMISSIONING						
2.1 SVE system removal (excl bldg)	L.S.	1	50,000	70,000	50,000	70,000
2.2 Seep system, fence, decon pad	L.S.	1	50,000	80,000	50,000	80,000
2.3 Debris disposal	cu. yd.	250	80	100	20,000	25,000
3.0 SOIL COVER CONSTRUCTION						
3.1 Site preparation, grading	acre	2.50	10,000	12,000	25,000	30,000
3.2 Fill for cap subgrade	cu. yd.	1,500	13	15	19,500	22,500
3.3 General Fill Layer (18-in)	cu. yd.	4,610	13	15	59,930	69,150
3.4 Topsoil Layer (6-in)	cu. yd.	1,540	18	25	27,720	38,500
3.5 Seeding/Mulching	acre	2.50	3,000	4,000	7,500	10,000
3.6 Sediment/Storm Water Controls	L.S.	1	40,000	60,000	40,000	60,000
4.0 SITE SECURITY						
4.1 Security fence	lin. ft.	3,300	18	20	59,400	66,000
5.0 SITE MANAGEMENT	months	4	15,000	20,000	60,000	80,000
Subtotal - Direct Construction Total (DCT)					$479,000	$631,000
Contractor's Indirect Costs (10% of non-process DCT)					$48,000	$63,000
Design, EPA Deliverables and Resident Engineering					$150,000	$200,000
Subtotal - Total Capital Cost (TCC)					$677,000	$894,000
Contingency (20% of TCC)					$135,000	$179,000
TOTAL CAPITAL COST					$812,000	$1,073,000
PRESENT WORTH O&M COST (from below)					$715,000	$715,000
TOTAL PRESENT WORTH PROJECT COST					$1,528,000	$1,788,000

Operation and Maintenance (O&M) Costs

ITEM DESCRIPTION (Annual Activities)	UNITS	QUANTITY	UNIT COST ($)			TOTAL COST ($)
6.0 AIR MONITORING, INSPECTION, REPORT	lump sum	1	25,000			25,000
7.0 COVER/FENCE/ROAD MAINTENANCE	lump sum	1	10,000			10,000
Total Annual Cost						35,000
Contingency (20%)						7,000
Subtotal						42,000
Present Worth annual O&M (30-yrs, i=5%)						645,624
Present Worth five-year review (i=5%)						69,550
Total Present Worth O&M						715,174

TABLE G-2 PROBABLE COST FOR ALTERNATIVE 2, CAPPING

Date: 11/4/94

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($) LOW	UNIT COST ($) HIGH	TOTAL COST ($) LOW	TOTAL COST ($) HIGH
1.0 MOBILIZATION/DEMOBILIZATION	L.S.	1	60,000	90,000	60,000	90,000
2.0 DECOMMISSIONING						
2.1 SVE system removal (excl bldg)	L.S.	1	50,000	70,000	50,000	70,000
2.2 Seep system, fence, decon pad	L.S.	1	50,000	80,000	50,000	80,000
2.3 Debris disposal	cu. yd.	250	80	100	20,000	25,000
3.0 CAP CONSTRUCTION						
3.1 Site preparation, grading	acre	2.50	10,000	12,000	25,000	30,000
3.2 Fill for cap subgrade	cu. yd.	1,500	13	15	19,500	22,500
3.3 Gravel gas vent layer (8-in)	cu. yd.	2,050	20	25	41,000	51,250
3.4 Piping for venting	ft.	2,660	6	8	20,000	25,000
3.5 Geotextile filter	sq. yd.	12,200	2	2.50	24,000	30,000
3.6 Compacted clay layer (24-in)	cu. yd.	6,150	30	40	184,500	246,000
3.7 General Fill Layer (18-in)	cu. yd.	4,620	13	15	60,060	69,300
3.8 Topsoil Layer (6-in)	cu. yd.	1,540	18	25	27,720	38,500
3.9 Seeding/Mulching	acre	2.50	3,000	4,000	7,500	10,000
3.10 Sediment/Storm Water Controls	L.S.	1	40,000	60,000	40,000	60,000
4.0 SITE SECURITY						
4.1 Security fence	lin. ft.	3,300	18	20	59,400	66,000
5.0 SITE MANAGEMENT	months	5	15,000	20,000	75,000	100,000

	LOW	HIGH
Subtotal - Direct Construction Total (DCT)	$764,000	$1,014,000
Contractor's Indirect Costs (10% of non-process DCT)	$76,000	$101,000
Design, EPA Deliverables and Resident Engineering	$175,000	$230,000
Subtotal - Total Capital Cost (TCC)	$1,015,000	$1,345,000
Contingency (20% of TCC)	$203,000	$269,000
TOTAL CAPITAL COST	$1,218,000	$1,614,000
PRESENT WORTH O&M COST (from below)	$1,132,000	$1,132,000
TOTAL PRESENT WORTH PROJECT COST	$2,350,000	$2,746,000

Operation and Maintenance (O&M) Costs

ITEM DESCRIPTION (Annual Activities)	UNITS	QUANTITY	UNIT COST ($)			TOTAL COST ($)
6.0 AIR MONITORING, INSPECTION, REPORT	L.S.	1	30,000			30,000
7.0 CAP/FENCE/ROAD MAINTENANCE	L.S.	1	10,000			10,000

Total Annual Cost	40,000
Contingency (20%)	8,000
Subtotal	48,000
Present Worth annual O&M (30-yrs, i=5%)	737,856
Present worth package SVE installation = $30,000, Year 10, i=5%	18,500
Present worth annual carbon/solvent disposal = $25,000, Year 11-30, i=5%	191,250
Present worth annual labor = $15,000, 1/4 time mechanic, Year 11-30, i=5%	114,750
Present Worth five-year review (i=5%)	69,550
Total Present Worth O&M	1,131,906

TABLE G-3   PROBABLE COST FOR ALTERNATIVE 3, WET SOIL COVER

Date: 11/4/94

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($)		TOTAL COST ($)	
			LOW	HIGH	LOW	HIGH
1.0 MOBILIZATION/DEMOBILIZATION	L.S.	1	60,000	80,000	60,000	80,000
2.0 DECOMMISSIONING						
2.1 SVE system removal (excl bldg)	L.S.	1	50,000	70,000	50,000	70,000
2.2 Seep system, fence, decon pad	L.S.	1	50,000	80,000	50,000	80,000
2.3 Debris disposal	cu. yd.	250	80	100	20,000	25,000
3.0 GROUND WATER CONTROL						
3.1 Additional monitoring wells	EA	5	6,000	8,000	30,000	40,000
3.2 Seepage control subdrain	EA	10	3,000	5,000	30,000	50,000
3.3 Upgradient cut-off drain	EA	1,000	12	25	12,000	25,000
4.0 COVER & INFILT BLANKET						
4.1 Site preparation, grading	acre	2.50	10,000	12,000	25,000	30,000
4.2 Wet Barrier Layer Prep. (18-in)	cu. yd.	4,610	5	8	23,050	36,880
4.3 Sand infiltration blanket (12-in)	cu. yd.	3,080	20	25	61,600	77,000
4.4 Subsurface irrigation system	L.S.	1	40,000	60,000	40,000	60,000
4.5 Geotextile filter	sq. yd.	9,300	2.00	2.50	18,600	23,250
4.6 General Fill Layer (6-in)	cu. yd.	1,540	13	15	20,020	23,100
4.7 Topsoil Layer (6-in)	cu. yd.	1,540	18	25	27,720	38,500
4.8 Seeding/Mulching	acre	2.50	3,000	4,000	7,500	10,000
4.9 Sediment/Storm Water Controls	L.S.	1	40,000	60,000	40,000	60,000
5.0 SITE SECURITY						
5.1 Security Fence	lin. ft.	3,300	18	20	59,400	66,000
6.0 SITE MANAGEMENT	months	5	15,000	20,000	75,000	100,000

	LOW	HIGH
Subtotal - Direct Construction Total (DCT)	$650,000	$895,000
Contractor's Indirect Costs (10% of non-process DCT)	$65,000	$89,000
Design, EPA Deliverables and Resident Engineering	$200,000	$270,000
Subtotal - Total Capital Cost (TCC)	$915,000	$1,254,000
Contingency (20% of TCC)	$183,000	$251,000
TOTAL CAPITAL COST	$1,098,000	$1,505,000
PRESENT WORTH O&M COST (from below)	$992,000	$992,000
TOTAL PRESENT WORTH PROJECT COST	$2,090,000	$2,497,000

Operation and Maintenance (O&M) Costs

ITEM DESCRIPTION (Annual Activities)	UNITS	QUANTITY	UNIT COST ($)			TOTAL COST ($)
7.0 AIR MONITORING, INSPECTION, REPORT	L.S.	1	25,000			25,000
8.0 COVER/FENCE/ROAD MAINTENANCE	L.S.	1	10,000			10,000
9.0 IRRIGATION SYSTEM O/M	L.S.	1	15,000			15,000

Total Annual Cost	50,000
Contingency (20%)	10,000
Subtotal	60,000
Present Worth annual O&M (30-yrs, i=5%)	922,320
Present Worth five-year review (i=5%)	69,550
Total Present Worth O&M	991,870

TABLE G-4 PROBABLE COST FOR ALTERNATIVE 4, ON-SITE LTTD

Date: 11/4/94

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($) LOW	UNIT COST ($) HIGH	TOTAL COST ($) LOW	TOTAL COST ($) HIGH
1.0 MOBILIZATION/DEMOBILIZATION	L.S.	1	150,000	250,000	150,000	250,000
2.0 DECOMMISSIONING						
2.1 SVE system removal (excl bldg)	L.S.	1	50,000	70,000	50,000	70,000
2.2 Seep system, fence, decon pad	L.S.	1	50,000	80,000	50,000	80,000
2.3 Debris disposal	cu. yd.	250	80	100	20,000	25,000
3.0 EXCAVATION & FEED PREPARATION						
3.1 Enclosure structure (installed)	set	1	180,000	220,000	180,000	220,000
3.2 Vent/vapor treatment system	set	1	50,000	70,000	50,000	70,000
3.3 Enclosure/air system O/M	months	8	1,700	2,000	13,600	16,000
3.4 Excavate, process, feed soil	tons	19,600	50	70	980,000	1,372,000
4.0 LTTD TREATMENT						
4.1 LTTD mob/demob	L.S.	1	300,000	450,000	300,000	450,000
4.2 Test run and approval	L.S.	1	250,000	350,000	250,000	350,000
4.3 Desorption treatment	tons	18,400	120	140	2,208,000	2,576,000
4.4 Chemical analysis	samples	1,000	200	300	200,000	300,000
4.5 VOC liquid disposal	tons	75.3	700	850	52,675	63,963
5.0 SOIL COVER						
5.1 Treated soil + boulder backfill	ton	19,600	9	11	176,400	215,600
5.2 Subgrade preparation	acre	2.5	3,000	4,000	7,500	10,000
5.3 General Fill Layer (18-in)	cu. yd.	4,610	13	15	59,930	69,150
5.4 Topsoil Layer (6-in)	cu. yd.	1,540	18	25	27,720	38,500
5.5 Seeding/Mulching	acre	2.50	3,000	4,000	7,500	10,000
5.6 Sediment/Storm Water Controls	L.S.	1	40,000	60,000	40,000	60,000
6.0 SITE SECURITY						
6.1 Security Fence	lin. ft.	3,300	18	20	59,400	66,000
7.0 SITE MANAGEMENT	months	12	30,000	40,000	360,000	480,000

	LOW	HIGH
Subtotal - Direct Construction Total (DCT)	$5,243,000	$6,792,000
Contractor's Indirect Costs (10% of non-process DCT)	$303,000	$422,000
Design, EPA Deliverables and Resident Engineering	$400,000	$530,000
Subtotal - Total Capital Cost (TCC)	$5,946,000	$7,744,000
Contingency (20% of TCC)	$1,189,000	$1,549,000
TOTAL CAPITAL COST	$7,135,000	$9,293,000
PRESENT WORTH O&M COST (from below)	$715,000	$715,000
TOTAL PRESENT WORTH PROJECT COST	$7,851,000	$10,008,000

Operation and Maintenance (O&M) Costs

ITEM DESCRIPTION (Annual Activities)	UNITS	QUANTITY	UNIT COST ($)			TOTAL COST ($)
8.0 AIR MONITORING, INSPECTION, REPORT	lump sum	1	25,000			25,000
9.0 COVER/FENCE/ROAD MAINTENANCE	lump sum	1	10,000			10,000

Total Annual Cost	35,000
Contingency (20%)	7,000
Subtotal	42,000
Present Worth O&M (30-yrs, i=5%)	645,624
Present Worth five-year review (i=5%)	69,550
Total Present Worth O&M	715,174

TABLE G-5   PROBABLE COST FOR ALTERNATIVE 5, OFF-SITE INCINERATION/DISPOSAL

Date: 11/4/94

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($) LOW	UNIT COST ($) HIGH	TOTAL COST ($) LOW	TOTAL COST ($) HIGH
1.0 MOBILIZATION/DEMOBILIZATION	L.S.	1	200,000	300,000	200,000	300,000
2.0 DECOMMISSIONING						
2.1 SVE system removal (excl bldg)	L.S.	1	50,000	70,000	50,000	70,000
2.2 Seep system, fence, decon pad	L.S.	1	50,000	80,000	50,000	80,000
2.3 Debris disposal	cu. yd.	250	80	100	20,000	25,000
3.0 EXCAVATION/SHIPPING						
3.1 Enclosure structure (installed)	set	1	180,000	220,000	180,000	220,000
3.2 Vent/vapor treatment system	set	1	50,000	70,000	50,000	70,000
3.4 Enclosure/air system O/M	months	4	1,700	2,000	6,800	8,000
3.5 Soil excavation	tons	19,600	35	50	686,000	980,000
3.6 Railroad loading track	L.S.	1	150,000	180,000	150,000	180,000
3.7 Loading dock construction	L.S.	1	70,000	90,000	70,000	90,000
3.8 Loading	tons	18,400	20	25	368,000	460,000
3.9 Transportation charge (Conrail)	tons	18,400	75	85	1,380,000	1,564,000
3.10 Loading dock demolition/disposal	L.S.	1	25,000	35,000	25,000	35,000
4.0 OFF-SITE INCINERATION Include test, treatment, disposal	tons	18,400	700	850	12,880,000	15,640,000
5.0 SOIL COVER						
5.1 Imported soil + boulder backfill	ton.	16,000	12	15	192,000	240,000
5.2 Subgrade preparation	acre	2.5	3,000	4,000	7,500	10,000
5.3 General Fill Layer (18-in)	cu. yd.	4,610	13	15	59,930	69,150
5.4 Topsoil Layer (6-in)	cu. yd.	1,540	18	25	27,720	38,500
5.5 Seeding/Mulching	acre	2.50	3,000	4,000	7,500	10,000
5.6 Sediment/Storm Water Controls	L.S.	1	40,000	60,000	40,000	60,000
6.0 SITE SECURITY						
6.1 Security Fence	lin. ft.	3,300	18	20	59,400	66,000
7.0 SITE MANAGEMENT	months	9	30,000	40,000	270,000	360,000

	LOW	HIGH
Subtotal - Direct Construction Total (DCT)	$16,780,000	$20,576,000
Contractor's Indirect Costs (10% of non-process DCT)	$390,000	$494,000
Design, EPA Deliverables and Resident Engineering	$400,000	$530,000
Subtotal - Total Capital Cost (TCC)	$17,570,000	$21,599,000
Contingency (20% of TCC)	$3,514,000	$4,320,000
TOTAL CAPITAL COST	$21,084,000	$25,919,000
PRESENT WORTH O&M COST (from below)	$715,000	$715,000
TOTAL PRESENT WORTH PROJECT COST	$21,799,000	$26,634,000

Operation and Maintenance (O&M) Costs

ITEM DESCRIPTION (Annual Activities)	UNITS	QUANTITY	UNIT COST ($)			TOTAL COST ($)
8.0 AIR MONITORING, INSPECTION, REPORT	lump sum	1	25,000			25,000
9.0 CAP/FENCE/ROAD MAINTENANCE	lump sum	1	10,000			10,000

Total Annual Cost	35,000
Contingency (20%)	7,000
Subtotal	42,000
Present Worth O&M (30-yrs, i=5%)	645,624
Present Worth five-year review (i=5%)	69,550
Total Present Worth O&M	715,174

Appendix H
Performance Evaluation of Wet
Soil Cover Alternative

PERFORMANCE EVALUATION OF WET SOIL COVER ALTERNATIVE
TABLE OF CONTENTS

LIST OF FIGURES

The wet soil cover alternative, consisting of a vegetated soil cover, an infiltration blanket, and a wet soil layer, is one of several remedial alternatives evaluated in the FFS. In this alternative, a layer of soil is kept very wet by introducing municipal water and/or treated ground water to form an effective barrier to upward vapor diffusion. The surface soil cover and the infiltration blanket layers will prevent dermal contact and ingestion of the lagoon soil. As a result, this alternative can address all risks from the lagoon soil. To meet the remedial action objectives, this alternative should meet the following requirements:

- A uniform and high level saturation of the wet soil layer and lagoon soil to minimize vapor phase diffusion;

- Minimize the changes in the local geohydrologic regime to prevent migration of ground water beyond the contaminated areas;

- Recovery of the water introduced into the lagoon soil via the existing french drain; and

- Contain any excess water introduced during precipitation events.

This appendix presents an analyses of the performance of this remedy in meeting the above requirements.

2.1   *EVALUATION APPROACHES*

VOC emissions from the lagoon area soils present potential inhalation exposure risks as discussed in Appendix F (Risk Assessment). The wet soil cover has two inherent functions to minimize vapor emissions from the lagoon soils. First, the wet soil layer will be almost saturated which will limit VOC migration to aqueous diffusion. Since the aqueous diffusion rate is about four orders of magnitude lower than the gaseous diffusion rate (e.g., TCP's air diffusion coefficient is 7.3E-2 cm^2/sec and water diffusion coefficient is 7.8E-6 cm^2/sec), the emission rate will also be four orders of magnitude lower. Second, percolating water will push the diffusion front downward, and virtually eliminate any possibility of upward flux through the wet soil cover.

The performance of the wet soil cover alternative in controlling vapor emissions are evaluated by three different approaches as listed below:

- Average air porosity method - estimation of diffusive flux reduction based on the average air-filled porosity of the soil layers above the contaminated lagoon soil.

- Layered soil air porosity method - estimation of diffusive flux reduction based on the air-filled porosity of the individual soil layers above the contaminated lagoon soil.

- Diffusion velocity method - comparison of the downward flow velocity of the percolating water through the wet soil layer and the upward velocity of the diffusion front.

In evaluating vapor diffusion through a soil layer, the air-filled porosity of the soil is the most important parameter. If the air-filled porosity is very low (0.05 or lower), vapor migration will be by aqueous diffusion. For air porosity values above 0.10, VOC migration is by gaseous diffusion and the flux rate varies proportionally with the air porosity. The air porosity of the cover soil layer is assumed to be about 0.2 as shown in Figure H-1. As free water is available in the infiltration blanket, the wet soil cover will be almost saturated and its air porosity may be assumed to be about 0.03. The air-filled porosity of the lagoon soil, during operation of the wet soil barrier, may be estimated using the principles of unsaturated flow and mass continuity.

The saturated hydraulic conductivity, K_s, of the lagoon soil is assumed to be 5×10^{-5} cm/sec. The wet soil cover can be built to have a target

Figure H-1
Subsurface Profiles and Air-Filled Porosity
Tyson's Site
Focused Feasibility Study
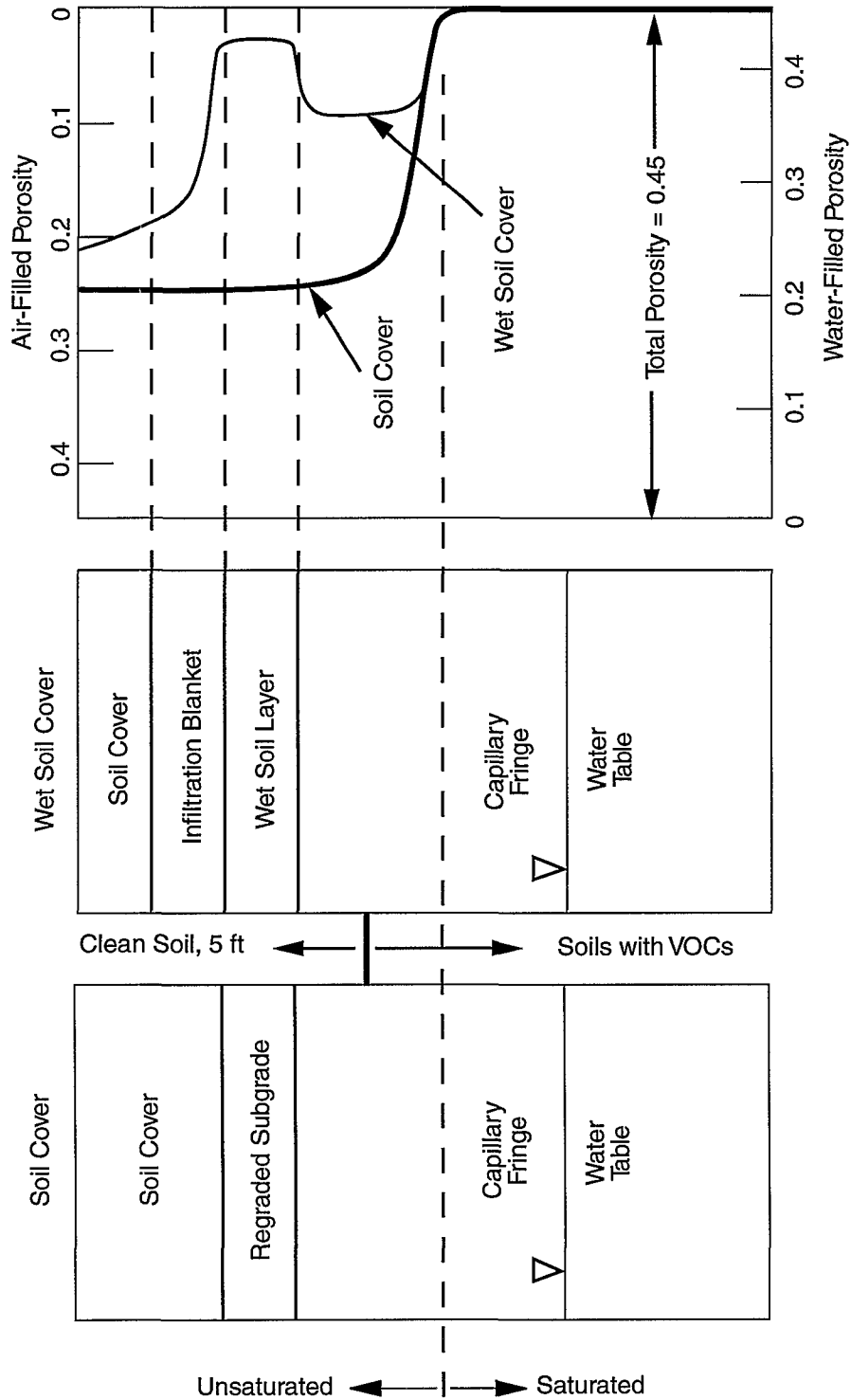
Note - Water-filled porosity curve for soil cover is a modification of Figures 2-12(a) and 2-12(b) from Freeze and Cherry (1979).
Water-filled porosity curve for wet soil cover is a modification of Figure 6 from Johnson et. al. (1983)

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saturated K_s of about 1×10^{-5} cm/sec or less. Thus, the wet soil layer will control the infiltration rate. The water should flow faster as it enters the lagoon soil having a higher K_s. Mass continuity requires fluid flowing out of the wet barrier layer to occur through a smaller flow area in the lagoon soil. This will result in lower saturation in the lagoon soil. As a soil gets less saturated, the unsaturated K_s decreases drastically. For a non-clay soil draining from an air-filled porosity of 0.0 to 0.1, the corresponding reduction of K_s is almost one order of magnitude (Bouwer, 1978). Thus, this reduction of K_s achieves the continuity of flow by making the lagoon soil k about equal to the wet barrier k (i.e., from saturated K_s of 5×10^{-5} cm/sec to unsaturated K_s of 1×10^{-5} cm/sec). From the K_s reduction required for flow continuity, the air porosity (θ_a) of the lagoon soil may be estimated as follows:

Wet soil layer at $\theta_a = 0.00$ (full saturation) $K_s = 1 \times 10^{-5}$ cm/sec

at $\theta_a = 0.03$ (assume no change) $K_s = 1 \times 10^{-5}$ cm/sec

Lagoon Soil at $\theta_a = 0.00$ (full saturation) $K_s = 5 \times 10^{-5}$ cm/sec

at $\theta_a = 0.03$ (assume no change) $K_s = 5 \times 10^{-5}$ cm/sec

at $\theta_a = 0.13$ (1/10 of original k) $K_s = 0.5 \times 10^{-5}$ cm/sec

at $\theta_a = 0.10$ (by graphical interpolation of θ_a vs. log k)

$K_s = 1 \times 10^{-5}$ cm/sec

In the above steps, the K_s values at $\theta_a = 0.00$ and $\theta_a = 0.03$ were assumed to be identical because the θ_a vs. log k relationship is generally sigmoid. The result of the above interpolation indicates that the air-filled porosity of the lagoon soil should be 0.10 to achieve a $K_s = 1 \times 10^{-5}$ cm/sec. These air porosities are used to evaluate the diffusion control performance in Section 2.2.

If subsequent site testing indicates that the lagoon area soils have a hydraulic conductivity different from the 5×10^{-5} cm/s assumed here, the previous discussion can be modified accordingly.

2.2   *LAYERED SOIL AIR POROSITY METHOD*

Vapor flux of organic chemicals by gaseous diffusion through soil may be estimated using Equations (1) and (2) based on Fick's Law as follows:

$J = D_e \, C_o / L$ (1)

$D_e = [D_a \, (\theta_a)^{10/3} / (\theta_t)^2]$ (2)

Where

J   vapor flux of the chemical through soil (g/sec.cm^2)

D_e effective diffusion coefficient of the chemical through soil air (cm^2/sec)

C_o concentration of the chemical in air at the source (g/cm^3)

L diffusion distance from the source to soil surface (cm)

D_a diffusion coefficient of the chemical in free air (cm^2/sec)

θ_t total porosity of the soil(unitless)

θ_a air-filled porosity of the soil (unitless)

In estimating the vapor flux for the soil cover alternative, the risk assessment report has used the following parameters:

Total porosity of the soil, $\theta_t = 0.45$

Air-filled porosity of the soil, $\theta_a = 0.25$

Diffusion distance (thickness of clean soil), $L = 150$ cm

Substituting these parameters into Equations (1) and (2) yields the flux rate for the soil cover alternative as follows:

$$J_s = 0.0486 D_a C_o / 150 \text{ (g/sec.cm}^2)$$

The wet soil cover alternative will create three distinct soil layers with different air-filled porosity as follows (see Figure H-1):

Layer 1   soil cover and upper half of the infiltration blanket,

         18 inch thick, air-filled porosity = 0.2

Layer 2   lower half of the infiltration blanket and the wet soil layer, 24 inch thick, air-filled porosity = 0.03

Layer 3   relatively clean lagoon soil immediately below the wet soil layer, 18 inch thick, air-filled porosity = 0.1

Using the above air-filled porosity values, the effective diffusion coefficient of each layer can be calculated as follows:

Layer 1 $D_{e1} = [D_a (0.2)^{10/3}/(0.45)^2] = 0.0231 D_a$

Layer 2 $D_{e2} = [D_a (0.03)^{10/3}/(0.45)^2] = 0.00004 D_a$

Layer 3 $D_{e3} = [D_a (0.10)^{10/3}/(0.45)^2] = 0.0023 D_a$

The flux rate through consecutive layers with different air filled porosities can be estimated by using a single diffusion coefficient and then calculating a transformed diffusion distance by the ratio of the diffusion coefficients.

Using the above method, the three layers in the wet soil cover alternative may be transformed as follows:

Layer 1	Use $D_{e1} = 0.0023D_a$ (1/10 of the real value)
	Convert $L_1 = 18$ in x $(1/10) = 1.8$ in
Layer 2	Use $D_{e2} = 0.0023D_a$ (57.5 times the real value)
	Convert $L_2 = 24$ in x $(57.5) = 1,380$ in
Layer 3	$D_{e3} = 0.0023D_a$, $L_3 = 18$ in
Three-layer effect	$D_e = 0.0023D_a$, $L = 1400$ in.

The resultant flux rate may be expressed as follows:

$$J_w = 0.0023D_aC_o/1400 \ (g/sec.cm^2)] = 0.005 \ J_s$$

Based on this layered soil diffusion analysis, the flux rate through the wet soil cover will be about 0.5% of the flux rate through the normal soil cover.

2.3   *DIFFUSION VELOCITY METHOD*

The presence of water in the infiltration blanket will keep the wet soil layer nearly saturated, resulting in a very low air-filled porosity. In this case, the air pores are isolated far apart and cannot provide continuous paths for vapor diffusion. Therefore, the diffusion process takes place through the pore water in the wet soil layer and the infiltration blanket. Diffusion of organic chemicals through water is extremely slow. If the downward flow velocity of the percolating water is much greater than the upward velocity of the diffusion front, chemicals cannot break through the wet soil layer and no vapor emissions are possible. This section compares these two velocities.

Calculation of the downward flow velocity is as follows:

Hydraulic conductivity of the wet soil layer, (assumed) 1×10^{-5} cm/sec

Hydraulic gradient (vertical percolation) $\qquad i = 1.0$

Porosity of soil, n $\qquad$ use n = 0.4

Flow velocity $\quad V = ki/n = 1 \times 10^{-5}$ cm/sec x $1.0/0.4 = 2.16$ cm/day

The movement of the diffusion front is governed by the one-dimensional, time-dependent diffusion process through a saturated soil. This process is described by the following equation (Freeze and Cherry, 1979):

$$C/C_0 = erfc \ [\ 0.5X/(D^* \ t)^{0.5}]$$

$$D^* = \omega D$$

Where:

C   concentration at time t and at distance X from the source

C_O chemical concentration at the source (X = 0)

erfc   complementary error function

X   distance between the point of interest and the source

D^* effective diffusion coefficient of chemical through soil water

ω empirical coefficient for effective diffusion through soil water (may use w = 0.15 for the wet soil layer)

D   diffusion coefficient of the chemical through free water

The above equation gives the concentration ratio at a certain distance and time, rather than the velocity of the diffusion front. However, the velocity of the diffusion front may be calculated using the following steps:

- Take the location where $C/C_O = 0.01$, a sufficiently low value larger than zero, as the diffusion front.

- Select a distance X_1 and calculate the corresponding time t_1.

- Select a second distance X_2 slightly larger than X_1 and calculate the corresponding time t_2.

- Calculate the velocity of the diffusion front using the two time values and the two distance values obtained in the above steps.

Using TCP as the representative chemical at the site, the following steps will calculate the time required for the diffusion front to move one cm upward at the mid-depth of the wet soil layer:

Thickness of the wet soil layer   45 cm

At mid depth of the wet soil layer   X = 23 cm

Aqueous diffusion coefficient of TCP $D = 7.8 \times 10^{-6}$ cm^2/sec

Effective diffusion coefficient of TCP through soil water
$$D^* = 0.15 \times D = 1.17 \times 10^{-6} \text{ cm}^2/\text{sec}$$

Take the diffusion front as the location where $C/C_O = 0.01$

From complementary error function table $C/C_O = 0.01 = $ erfc (1.825)

From diffusion equation $0.5X/(D^* t)^{0.5} = 1.825$ and $t = (X/3.65)^2/D^*$

For X = 23 cm, $t = (23/3.65)^2/(1.17 \times 10^{-6}) = 34 \times 10^6$ sec = 394 days

For X = 24 cm, $t = (24/3.65)^2/(1.17 \times 10^{-6}) = 37 \times 10^6$ sec = 428 days

The time to move 1 cm at X = 23 cm   428 - 394 = 34 days

The above analysis indicates that the downward velocity of flushing water (2.16 cm/day) is 72 times faster than the possible upward velocity of the diffusive front (0.03 cm/day) at the mid-depth of the wet soil layer. Therefore, the leading front of the diffusion plume cannot even reach the mid-depth of the wet soil layer. As a result, VOC emissions would not occur through the wet soil layer.

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As water is introduced through the wet soil cover, the water table beneath the lagoon area will rise. An excessive rise of the water table may cause two potential problems: raise the (contaminated) water table into the clean soil zone, and increase the seepage along the north high wall. This section evaluates the potential for these problems and engineering control measures to handle the problem in three steps.

> Step 1 - evaluate the current ground water flow conditions beneath the lagoon area to be covered by the wet soil cover.

> Step 2 - determine an acceptable flow rate through the wet soil cover without causing the potential problems.

> Step 3 - evaluate potential operational and engineering control measures to prevent the problems.

3.1   *CURRENT GROUND WATER FLOW CONDITIONS*

Figure H-2 shows the ground water profiles for the natural condition and during the wet soil cover operation. Depending on the location, the current ground water table is estimated to be about 5 to 15 ft below the ground surface. The current flow rate of ground water through the bedrock zone under the lagoon area may be estimated by idealizing the site conditions. The lagoon area is relatively long and narrow. This site setting may be represented as a one-dimensional flow problem as follows (excluding the Lower East Lagoon area):

Ground water flow width beneath the lagoon area	750 feet
Thickness of bedrock flow zone (assumed)	40 feet
Bedrock hydraulic conductivity (from ERM-2S and ERM-3S completed in shallow bedrock, ERM, 1987)	1.2 ft/day
Typical hydraulic gradient beneath the lagoon area	0.16

Ground water flow rate $Q = kiA = 1.2 \text{ ft/day} \times 0.16 \times 750 \text{ ft} \times 40 \text{ ft}$
$$= 5{,}760 \text{ ft}^3/\text{day} \ (30 \text{ gpm})$$

3.2   *ACCEPTABLE FLOW RATE THROUGH THE WET SOIL COVER*

The water table rise due to the wet soil cover operation will be gradual from upgradient to downgradient: minimal rise along the southern limit of the lagoon and maximum rise along the northern limit of the lagoon as

Figure H-2
Geohydrologic Impact of Wet Soil Cover
Tyson's Site
Focused Feasibility Study
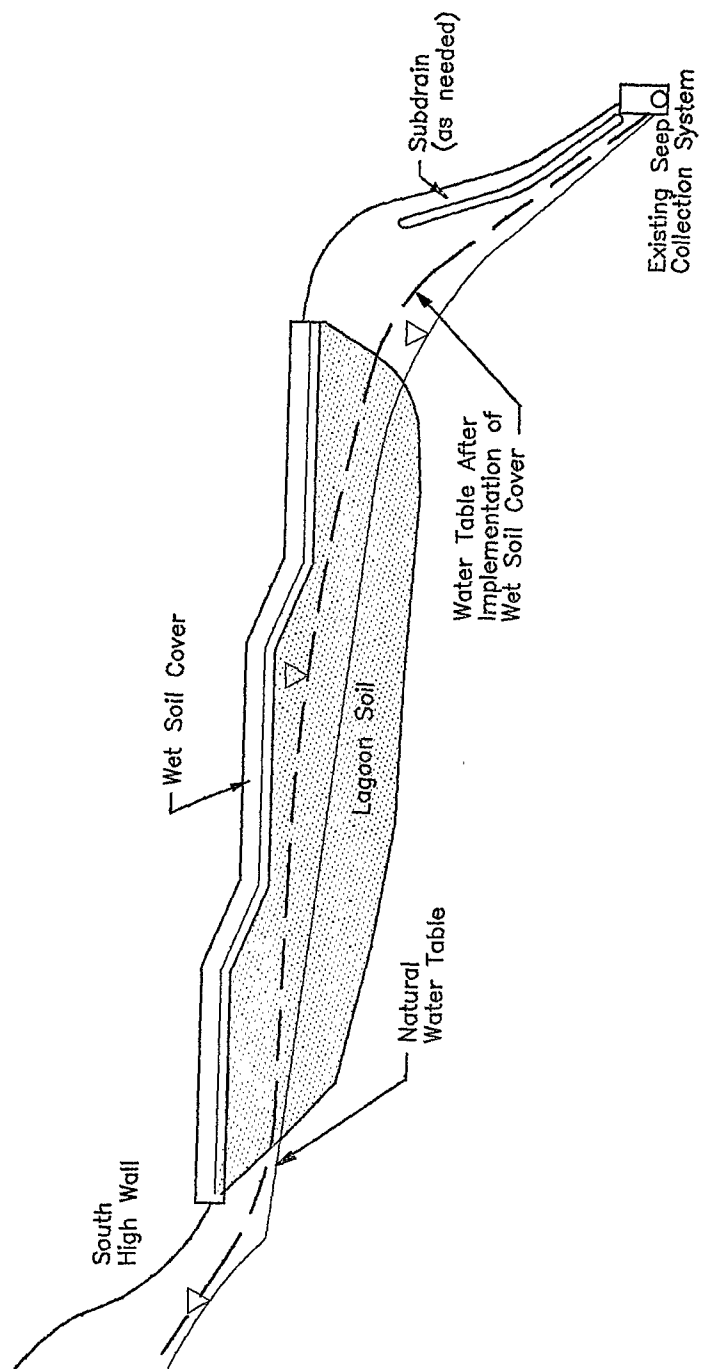
shown on Figure H-2. The critical area is along the northern limit where the water table rise may break out of the northern high wall. The typical water level and topography indicate that about 5 feet rise in the water table in this area may be acceptable. The rise of water table by 5 feet will cause a corresponding increase in the ground water flow area and hydraulic gradient, leading to an increase in the ground water flow rate as follows:

Ground water flow width beneath the lagoon area	750 feet
Thickness of bedrock flow zone	45 feet
Bedrock hydraulic conductivity (from ERM-2S and ERM-3S completed in shallow bedrock, ERM, 1987)	1.2 ft/day
Typical hydraulic gradient after water table rise	0.18

Ground water flow rate $\quad Q = kiA = 1.2$ ft/day $\times 0.18 \times 750$ ft $\times 45$ ft
$$= 7290 \text{ ft}^3/\text{day } (38 \text{ gpm})$$

Based on this flow rate and the current flow rate of 30 gpm, the acceptable recharge rate through the wet barrier is 8 gpm. However, the 8-gpm recharge rate may raise the water table by only 3 or 4 feet because the rising water table in the lagoon will cause a rise in the water table in the lower east lagoon and support zone and increase the flow rates in those areas.

3.3   OPERATION AND ENGINEERING CONTROL MEASURES

When the top of the wet soil layer is continuously flooded, the maximum flow rate possible through the wet soil cover is as follows:

Hydraulic conductivity of lagoon soil, assumed	5×10^{-5} cm/sec
Hydraulic conductivity of the wet soil layer	1×10^{-5} cm/sec
	= 0.028 ft/day
Hydraulic gradient (vertical percolation)	1.0
Wet soil cover area (from FFS Figure 3-1)	83,000 sf
Maximum flow rate through the wet soil layer	$Q = kiA$

$$= 0.028 \times 1.0 \times 83,000 \text{ ft}^2 = 2324 \text{ ft}^3/\text{day} = 12 \text{ gpm}$$

Since the acceptable infiltration rate through the wet barrier (8 gpm) is less than this maximum rate, the infiltration blanket should not be flooded continuously. To allow for the operational flexibility and uncertainty in the site conditions, the wet soil cover alternative should be designed with the operational and engineering considerations discussed below.

3.3.1　Recharge Rate

The average infiltration rate should be about 5 gpm. This rate may be achieved by intermittent recharges during normal to dry periods, reduced recharge during wet periods and no recharge during the winter months. This reduced recharge rate will raise the water table by about 2 to 3 feet along the northern limits of the lagoon area.

This operation recharge rate (5 gpm) is equivalent to a downward flow velocity of 0.9 cm/day, about 30 times the possible upward velocity of the diffusion front. For 100 days of no recharge in the winter, the diffusion front may move 3 cm upward. Therefore, the suggested operation will not adversely affect the diffusion control performance.

3.3.2　Subdrains Along the Northern High Wall

Although the recharge rate into the lagoon area (5 gpm) is very low, the fracture-controlled flow paths along the northern high wall may allow seeps at some locations. The seep locations on the high wall cannot be predicted. After an initial period of operation and monitoring, the seeps may be controlled by installing shallow subdrains as shown on Figure H-2.

3.3.3　Water Table Monitoring

The water table depth should be monitored by monitoring wells or tensiometers to detect the rising water table. When the water table rises above the predetermined level, water recharge may be temporarily cut off to prevent excessive water level rise.

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